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**Ship  
Structure  
Committee**

An Interagency Advisory Committee  
Dedicated to the Improvement of Marine Structures

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**ADVANCED METHODS FOR SHIP  
MOTION AND WAVE LOAD PREDICTION**

Advanced numerical methods are needed by ship designers to better predict and simulate ship motions and hull girder loads. Complex structural loading problems such as bottom slamming, bow flare impact, and green water on deck cannot be satisfactorily analyzed using linear strip theory.

This report provides a numerical method for predicting transient three-dimensional hydrodynamic pressures and resulting loads. This work is based on an initial level of investigation and development, and will require further testing, validation, and refinement of the numerical methods and computer programs.

J. D. Sipes  
Rear Admiral, U. S. Coast Guard  
Chairman, Ship Structure Committee



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16. Abstract  A numerical method for the simulation of ship motions, hull girder loads and transient three-dimensional hydrodynamic pressure is developed. A time-step intergration of the equations of motion is performed with sectional hydrodynamic forces computed using strip theory and buoyancy forces evaluated over the instantaneous immersed hull. In addition to hydrostatic and dynamic buoyancy forces, ship motion induced and wave diffraction forces, the method can also account for "flare" force and quadratic damping forces. The numerical model also has several features which may provide for more realistic simulations. Linear wave theory is assumed for the representation of the incident wave field, and regular and irregular, unidirectional or multidirectional wave systems can be generated.  A method for the prediction of transient three-dimensional hydrodynamic pressures extending the technique developed by R. B. Chapman is presented. Initial and boundary values for the pressure simulation are simultaneously generated from the solution of the equations of motion using sectional force computations. An option exists in the program to substitute the three-dimensional pressures for the two-dimensional hydrodynamic forces.  The work presented herein represents an initial level of investigation and development. The numerical methods and computer programs require further testing, validation and improvement.		
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METRIC CONVERSION FACTORS

Approximate Conversions to Metric Measures			
Symbol	What You Know	Multiply by	To Find
			<u>LENGTH</u>
m	inches	.025	centimeters
	feet	.30	metres
ft	yards	.93	kilometers
	miles	1.6	
			<u>AREA</u>
$\text{in}^2$	square inches	.65	square cm
$\text{ft}^2$	square feet	.090	square m
$\text{yd}^2$	square yards	.83	square km
$\text{mi}^2$	square miles	2.5	square kilometers
	acres	0.4	hectares
			<u>MASS (weight)</u>
	ounces	.29	grams
	pounds	.68	kilograms
	other tons (2000 lbs)	0.9	tonnes
			<u>VOLUME</u>
$\text{in}^3$	teaspoons	5	milliliters
$\text{ft}^3$	tablespoons	16	milliliters
$\text{yd}^3$	fluid ounces	30	milliliters
$\text{mi}^3$	cups	6.24	liters
	gallons	0.67	liters
	gallons	0.95	liters
	cubic foot	3.0	cubic meters
	cubic yards	0.03	cubic meters
		0.76	cubic meters
			<u>TEMPERATURE (heat)</u>
$^{\circ}\text{F}$	temperature	0.56 (after subtracting 32)	$^{\circ}\text{Celsius}$
			$^{\circ}\text{Fahrenheit}$

Units of Strength and Measures. Price 12.25. SD Catalog No. C12.10.286.

METRIC CONVERSION FACTORS

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## NOMENCLATURE

### Equations of Motion and Strip Theory

$A_{jk}$	= components of added mass matrix
$B_{km}$	= transformation matrix for Eulerian angles
$B M_y(x_0)$	= vertical bending moment at $x_0$
$B M_z(x_0)$	= horizontal bending moment at $x_0$
$F_j$	= external forces
$I_{jk}$	= components of moment and product of inertia matrix
$K$	= roll moment
$M$	= pitch moment
$M_{jk}$	= components of mass matrix
$M_s$	= ship's mass
$N$	= yaw moment
$R_G$	= vector position of ship c.g. in space system
$SF_y(x_0)$	= vertical shear force at $x_0$
$SF_z(x_0)$	= horizontal shear force at $x_0$

## NOMENCLATURE (Continued)

$s_i, c_i$	= sine and cosine components of force fluctuation for wave component $i$ , the relative magnitudes of which provide the proper phase relationship of all wave-related forces
$T_j$	= external moments
$T_M(x_0)$	= torsional moment at $x_0$
$U$	= ship's speed
$v_{G_k}$	= translational velocities of center of mass in space fixed system
	= $\frac{d}{dt} (R_G)$
$X$	= longitudinal force
$Y$	= vertical force
$Z$	= lateral force
$x_b^s \dots m_b^s$	= hydrostatic force components of the Froude-Krylov force
$x_{3D} \dots m_{3D}$	= force components calculated from the three-dimensional pressure computations
$a_i$	= amplitude of $i^{th}$ wave component
$a_{22}$	= heave added mass
$a_{33}$	= sway added mass

NOMENCLATURE (Continued)

- $a_{34}$  = section roll added mass moment of inertia due to sway motion
- $a_{44}$  = sectional roll added mass moment of inertia
- $b_{22}$  = heave damping coefficient
- $b_{33}$  = sway damping coefficient
- $b_{34}$  = sectional roll damping moment coefficient due to sway motion
- $b_{44}$  = sectional roll damping coefficient
- $b$  = Froude-Krylov force subscript
- $\frac{dy_h}{dx}, \frac{dz_h}{dx}, \frac{dk_h}{dx}$  = sectional ship motion-induced hydrodynamic force in heave sway and roll
- $\frac{dy_w}{dx}, \frac{dz_w}{dx}, \frac{dk_w}{dx}$  = sectional diffraction force in heave, sway and roll
- $f$  = "flare" force subscript
- $h$  = ship motion-induced force subscript
- $h_{cg}$  = vertical distance from waterline to ship c.g.  
(+ up).
- $i_N$  = wave index, total number of wave components
- $i_x$  = local section's mass moment of inertia
- $k_i$  = horizontal vector wave number

NOMENCLATURE (Continued)

$\hat{k}_i \hat{x}_i$	= $xk_i \cos\beta - zk_i \sin\beta$
$\hat{k}_i$	= projection of the wave number onto the x-axis of ship
$q$	= quadratic damping force subscript
$t$	= total force
$w$	= wave diffraction force subscript
$x$	= longitudinal distance to section from ship's c.g.
$\hat{x}_i$	= horizontal cartesian coordinates
$\bar{y}$	= local section's center of gravity relative to ship c.g. (positive up).
$y_G, z_G$	= heave and sway velocity of center of mass of ship
$\beta$	= direction of wave propagation
$\omega_i$	= circular frequency
$\epsilon_i$	= phase angle
$\omega_k$	= rotational velocities = $B_{km} \frac{d\alpha}{dt}$
$\psi, \dot{\psi}$	= Eulerian pitch angle and velocity in ship system
$\phi, \dot{\phi}$	= Eulerian yaw angle and velocity in ship system

## NOMENCLATURE (Continued)

$\theta, \dot{\theta}$	= Eulerian roll angle and roll velocity in ship system
$\xi_i, \dot{\xi}_i$	= average vertical water velocity, acceleration
$\zeta_i, \dot{\zeta}_i$	= average lateral water velocity, acceleration
$\kappa_i, \dot{\kappa}_i$	= average roll water velocity, acceleration
$\xi_i, \dot{\xi}_i$	= average vertical water velocity, acceleration
$\zeta_i, \dot{\zeta}_i$	= average lateral water velocity, acceleration
$\kappa_i, \dot{\kappa}_i$	= average roll water velocity, acceleration
$\mu$	= vertical sectional added mass gradient

### Three-dimensional Analysis

$A_{nm}, B_{nm}$	= complex functions of wave numbers and time
$A_{nm}^*, B_{nm}^*$	= complex conjugates
$A_i(t)$	= area of panel i
$E_{ij}$	= source - velocity influence matrix
$L_x, L_y, l_x, l_y, T$	= parameters for computing spectral free-surface representation wave numbers and spacing
$\hat{P}_{ij}$	= source - potential influence matrix

## NOMENCLATURE (Continued)

$p_T, p_B, p_{FS}, p_A$	= pressure at panel center, total, body, free-surface, ambient
$X_{ij}$	= source - x velocity influence matrix
$a_T, a_B, a_{FS}, a_A$	= acceleration vector
$k_{nm}$	= $k_{nm}^2 = kx_n^2 + ky_m^2$
$kx_n, ky_m$	= wave numbers in x and y; e.g., $\frac{\omega_n^2}{g}$
$s_i(t)$	= strength of source at panel i
$v_T, v_B, v_{FS}, v_A$	= velocities vector at panel centers, total, body-induced, free-surface and ambient wave
$v_x, v_z, a_x, a_z$	= x and z components of ambient wave-induced velocity and acceleration at panel center
$\phi_T$	= total time varying potential
$\phi_B$	= instantaneous effect on the body
$\phi_{FS}$	= free surface disturbance due to previously radiated and diffracted waves
$\phi_A$	= ambient wave potential
$\sigma_i$	= source density of panel i
$\Delta kx_n, \Delta ky_m$	= wave number spacing; e.g., $\Delta kx_n = kx_{n+1} - kx_n$

## NOMENCLATURE (Continued)

$$\omega_{nm}^2 = g [k_x_n^2 + k_y_m^2]^{1/2}$$

$\Delta A_{nm}^{BODY}$ ,  $\Delta A_{nm}^{BODY*}$ ,  $\Delta B_{nm}^{BODY}$ ,  $\Delta B_{nm}^{BODY*}$

= influence of body on free surface spectral component

**ADVANCED METHODS FOR  
SHIP MOTION AND WAVE  
LOAD PREDICTION**

**VOLUME 1**

## 1.0 INTRODUCTION

While the established ship motion and loading methods currently used in design practice remain indispensable, there is need for a more advanced tool that can carry the ship designer a step closer toward a fully rational ship design procedure. Although the application of linear strip theory in the frequency and probabilistic domains has met with remarkable success, there are a number of practical seakeeping and structural loading problems not satisfactorily analyzed by such techniques. Green water, bow flare impact and bottom slamming are particularly obvious examples. Reported large differences in dynamic sagging and hogging moments in some type of ships is a consequence of nonlinear loading [1,2]. The accurate prediction of rolling amplitudes requires the use of a nonlinear restoring moment at a large angle and nonlinear viscous damping estimates. These examples tend to highlight the generally nonlinear character of the ship motion and loads problem. An equally important part of the problem is its three-dimensionality. For example, the prediction of hydrodynamic pressures on the ship's hull below the mean waterline using linear two- and three-dimensional methods is not at a consistent level of accuracy. Clearly, there are a number of areas where improvements can be made in ship motion and loading prediction.

Based on an extensive review of the reported advanced methods in body-wave hydrodynamics and ship motion/loads prediction, a time-domain simulation of ship motion, hull girder loads and hydrodynamic pressures has been developed. Strip theory with certain nonlinear enhancements is used to predict sectional hydrodynamic forces for motion and hull girder loading prediction, and a three-dimensional source distribution of the hull, combined with a spectral representation of the free surface is used for the evaluation of hydrodynamic hull pressures. Linear wave theory is used and some optional numerical features have been included that may improve the predictions in some cases. The time-domain numerical simulation technique using strip theory-derived forces expands upon the capsizing simulation work of Oakley, Paulling, Wood and others [3]. In that method, the hydrodynamic forces from ship motion and diffraction are assumed to be small due to low encounter frequency in following and quartering waves -- allowing for approximate formulations. On the other hand, the Froude-Krylov forces (hydrostatic and dynamic buoyancy) are computed very accurately for the instantaneous immersed hull. In the present model, this accurate approach to Froude-Krylov forces has been used, while the ship motion and diffraction-induced forces are formulated according to standard strip theory equations [4].

Three-dimensional hull pressures and resultant loads are computed by a separate method based on Chapman's techniques for the simulation of arbitrary linearized motions of a floating body [5,6]. The present method extends Chapman's formulation to include ambient wave field and associated diffraction effects. Although the three-dimensional technique can be generalized to include a time-dependent hull shape, the computational method has been developed here in as simple a form as possible. Thus, as presently established, the hull is specified by surface panels describing the hull portion directly beneath the static-waterline only. The computational method can be easily expanded to include the entire hull; however, at present the computational effort to run a program with such an extension would be prohibitively expensive.

Several optional features have been incorporated into the numerical simulation procedures. Sectional added mass and damping coefficients may be evaluated for the instantaneous average sectional draft at each time step. Also the frequencies at which the added mass and damping coefficients are evaluated (for ship motion-induced forces) can be selected to correspond to either (a) the peak frequencies of motion response spectra, or (b) allowed to vary based on the measured response of the vessel during the previous two cycles of motion. Additionally, a vertical velocity-squared term is included in the strip formulations to partially account for the effect of flare impact loading. Finally, the simulation can incorporate the effects of velocity-squared damping using quadratic damping coefficients selected by the user.

It should be pointed out that because the majority of the testing and validation efforts described in this report use regular waves, the reader may tend to form the impression that the method is limited to regular waves. This is not the case. The incident wave system may be irregular and multidirectional. It is constructed from the superposition of regular waves, the amplitudes, frequencies, directions and phases of which may be specified by the user. They can thus be selected to represent the time history associated with any given sea spectrum.

This document (Volume I) describes the method and presents some test and validation results. Several computer programs were written to implement the approach and a user's manual (Volume II) is provided as a companion report.

## 1.1 BACKGROUND

In recent years, a number of impressive advances have been made in body-wave hydrodynamics. In particular, the fast-growing field of numerical ship hydrodynamics is producing a wide range of promising techniques with the potential to handle difficult nonlinear three-dimensional hydrodynamic phenomena. It is enlightening to follow the progress made by various investigators as presented in the First, Second and Third International Conferences on Numerical Ship Hydrodynamics in 1975, 1977 and 1981, respectively. Some of those efforts and others pertinent to the ship motion problem will be noted.

Efforts towards quasi-analytical solutions to Laplace's equation using singularity distributions for the ship motion problem have been reported by Chapman [6] and Chang [7]. M.S. Chang represents the ship hull by source/dipole distributions and solves the fluid domain and free surface equations using a mean hull boundary condition. It is a frequency-domain solution and appears to be an excellent way to find the correct linear wave excitation load distribution along the ship for any heading, speed and wave length. Solutions in the frequency domain assume that the response of the body to excitations of varied frequency content may be represented as the linear summation of responses to a series of discrete frequencies. Thus the equations of motion need to be solved only for the component frequencies. In contrast, in a time-domain solution, a time-history of the excitation is decomposed into a series of time steps with the time history of the response constructed by re-solving the equations of motion at each time step. R.B. Chapman's method is a time-domain computation somewhat analogous to Chang's approach. However, it does

not use Green's functions representing solutions of the free surface equations for oscillating singularities moving with uniform speed as does Chang. Simple sources and their image are used to represent the hull. Although the problem is linearized, the method is theoretically capable of accounting for a time-dependent hull shape. It thus provides the flexibility of arbitrary motions.

Another effort using singularity distributions includes that of Pettersen [8]. Pettersen's work is particularly interesting. As the problem is now formulated, he solves the integral equation at zero frequency for three-dimensional sources over the bow and stern and two-dimensional sources using strip theory for the middlebody. The approach has applications for ship maneuvering analysis but some work is being done for  $\omega \neq 0$ . Methods of finite difference potential field solutions to a free surface and wave problems have been reported by von Kerczek [9] and McCormick and J.W. Thomas [10], to mention only a few.

Bai [11] has continued to develop a finite element method applied to a three-dimensional harmonic ship-motion problem. The computational domain is reduced to a very small local domain using an eight-node three-dimensional element. The work is a direct extension of the earlier work by Bai and Yeung [12]. Other studies of finite element method applied to time harmonic ship motion problems have been presented by Chen and Mei [13], Seto and Yamamoto [14], Yue, Chen and Mei [15] and Chowdbury [16]. Emphasis in these cases is on the solution of regular harmonic motions, although finite element techniques have also been applied to transient problems by J.T. Beale [17] and C. Licht [18]. A. Jami and M. Lenoir [19] present a method for coupling finite elements and an integral representation.

Limited improvements to strip theory in the area of wave excitation and diffraction effects have been reported by S.O. Skjordal [20], and Troesch [21].

Research in the area of incompressible viscous flow has yielded several interesting techniques. Bourianoff and Penumalli [22] have developed a three-dimensional time-dependent ship motion simulation using a method they call the Inertial Marker Particle (IMP) technique. It is a Eulerian approach. A Eulerian approach uses a space-fixed reference system through which the fluid flows. In the alternate Lagrangian description, the reference frame moves with the fluid. A Lagrangian approach to transient-free surface flows was reported by Fritts and Boris [23]. Nichols and Hirt [24] report on progress being made with variants and improvements of the original Marker-and-Cell method in free-surface computations.

In the area of ship motion and loads prediction, the more advanced methods incorporate a time-simulation approach using some form of strip theory. The primary motivation for the development of this class of simulation programs is to account for nonlinearities from various sources. Paulling, Oakley and Wood [3] were interested in the capsizing problem with emphasis on accurate computation of buoyancy forces. Chang [25] developed a motion simulator emphasizing non-rigid body structural response to regular head seas. Meyerhoff and Schlacter [26] emphasized the dynamic whipping response due to bottom and flare impact in unidirectional irregular head seas. Borresen and

Telsgard [27] emphasized the nonlinear effects of bow flare on motions and rigid body hull girder loads. In the last three references, the relative motion hypothesis is employed in each case, and the frequencies at which the hydrodynamic coefficients are evaluated are usually the frequency of encounter ( $\omega_e$ ) or infinite frequency ( $\omega_\infty$ ). Also, the methods in the last three references treat only pitch and heave in unidirectional regular waves.

In view of these reported successes with the time-step solution to the equations of motion and the method's general capability of incorporating loads of a nonlinear character, this approach will be used as the basis of the present model. It is also intended that some type of three-dimensional hydrodynamic formulation cast as an initial value problem would be integrated with the motion simulator from which initial and boundary values would be specified. As noted before, a finite difference solution to the Euler equation was initially chosen based on the reported successes of Bourianoff and Penumalli [22]. The technique developed to apply this finite difference solution is described in [28]. The fundamental difficulty with using this technique for ship motion and transient-free surface simulation was the conflicting demands of numerical stability vs. realistic fluid dynamics. The finite difference Euler equation solution method was abandoned after it became apparent that some of the numerical difficulties could not be overcome within the scope of this project. Alternative methods were investigated, and the technique developed by R.B. Chapman reported in [6] was selected because of its ability to predict three-dimensional flow and handle arbitrary motions and time-dependent hull shapes. Its principal disadvantage is the fact that it is computationally demanding, requiring long run times.\* Nevertheless, in view of the ever-increasing capabilities of modern computational hardware, the use of the Chapman method and others like it should become practical in the near future.

---

\* Prescribed motion of a 120-panel body requires 7 CPU minutes per time step (0.1 sec < t < 0.25 sec) on a DEC VAX 11/750 or roughly 20-25 CPU secs on a so-called supercomputer (e.g., CRAY or CDC STAR).

## 2.0 THEORETICAL MODEL

### 2.1 GENERAL FORMULATION OF EQUATIONS OF MOTION

The equations of motion for the ship can be derived from Newton's second law and formulated as four first-order ordinary differential equations, the solution of which gives translational and rotational displacements and velocities. Solution is accomplished in a time-step fashion using a fourth-order Runge-Kutta integration scheme. The external forces and moments called for in the equations of motion are calculated using an extension of basic strip theory to derive ship motion-induced and diffraction forces. Froude-Krylov forces are computed using a volume integral approach over the instantaneous immersed hull. The incident wave system is represented by one or more linear waves of arbitrary amplitude, direction, frequency and phase relationship.

The ship is considered to be advancing with forward speed with an arbitrary heading in a system of sinusoidal waves of various amplitudes, frequencies and directions. Let  $(x, y, z)$  be a Cartesian coordinate system fixed in space. Let  $(x', y', z')$  be a Cartesian coordinate system fixed with respect to the ship, whose axes coincide with the principal axes of inertia of the ship and whose origin corresponds to the ship's center of mass. The direction of the axes are illustrated in Figure 1a.

The position of the ship in space is completely characterized by the position of the ship's mass center and the angular displacement of the ship. Eulerian angles will be used to describe angular displacement. Figure 1b shows the convention for the Eulerian angles.

The motion of the ship in an inertial frame of reference, according to Newton's second law, can be formulated using subscript notation as

$$\frac{d}{dt} M_{jk} V_{G_k} = F_j \quad (j = 1, 2, 3) \quad (1)$$

$$\frac{d}{dt} I_{jk} \omega_k = T_j \quad (j = 1, 2, 3) \quad (2)$$

in which

$M_{jk}$  = components of mass matrix

$I_{jk}$  = components of moment and product of inertia matrix

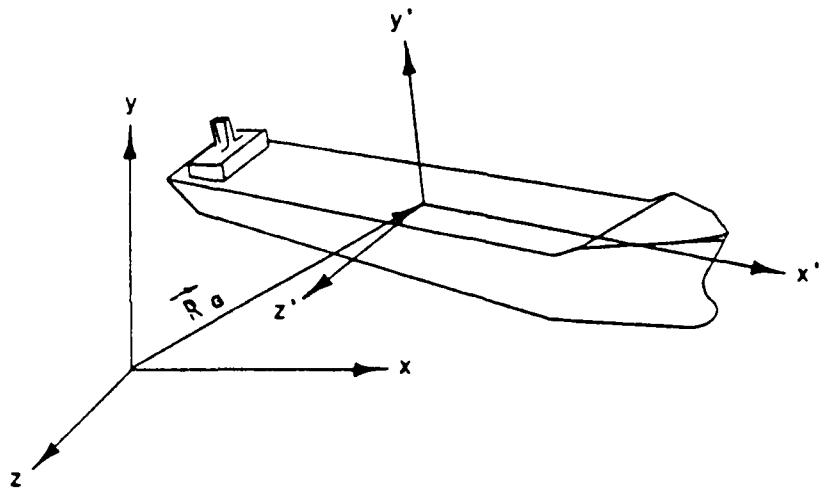


Figure 1a Axes for Solution of Equations of Motion

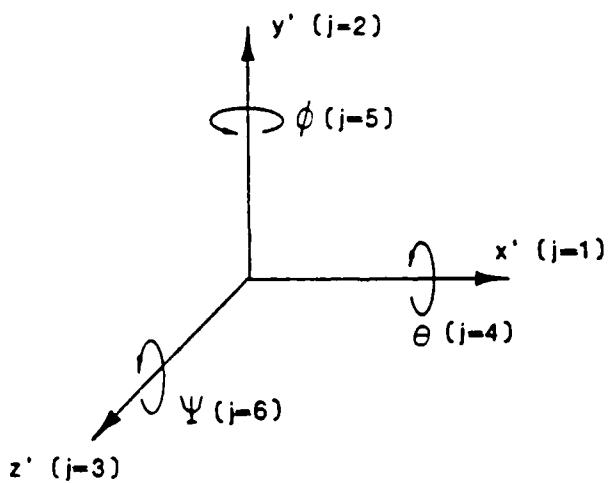


Figure 1b Sign Convention for Translational and Rotational Motions

$v_{G_k}$  = translational velocities of center of mass in space fixed system

$$= \frac{d}{dt} R_G$$

$\omega_k$  = rotational velocities

$$= B_{km} \frac{d\alpha_m}{dt}$$

and

$$B_{km} = \begin{bmatrix} 1 & \sin \psi & \theta \\ 0 & \cos \theta \cos \psi & \sin \theta \\ 0 & -\sin \theta \cos \psi & \cos \theta \end{bmatrix}$$

$$\alpha_m = \{ \theta, \phi, \psi \}$$

$\theta$  = Eulerian roll angle

$\phi$  = Eulerian yaw angle

$\psi$  = Eulerian pitch angle

$F_j$  = external forces

$T_j$  = external moments

In the ship coordinate system, the left side of equation (2) takes the following form:

$$\frac{d}{dt} (I_{jk} \omega_k) = I_{jk} \frac{d}{dt} \omega_k + \omega_k \times I_{jk} \omega_k \quad (3)$$

This is the Eulerian equation of motion whose application makes possible the use of constant moments and products of inertia. In the inertial frame of reference, these values are continuously changing.

Equations (1), (2) and (3) can be manipulated to yield the following two sets of two first-order ordinary differential equations:

$$\frac{d}{dt} x_{G_k} = v_{G_k} \quad (k = 1, 2, 3) \quad (4)$$

$$\frac{d}{dt} v_{G_k} = (M_{jk})^{-1} F_j \quad (k = 1, 2, 3) \quad (5)$$

$$\frac{d}{dt} \alpha_m = (B_{km})^{-1} \omega_k \quad (m = 1, 2, 3) \quad (6)$$

$$\frac{d}{dt} \omega_k = (I_{jk})^{-1} \{ T_j - \omega_k \times I_{jk} \omega_k \} \quad (k = 1, 2, 3) \quad (7)$$

Assuming that the ship has lateral symmetry, the mass matrix is given by

$$M_{jk} = \begin{bmatrix} M_s & 0 & 0 \\ 0 & M_s & 0 \\ 0 & 0 & M_s \end{bmatrix} + A_{jk} \quad (j = 1, 2, 3) \quad (8)$$

where  $A_{jk}$  represents added mass. The ship's mass is shown as  $M_s$  within the brackets.

The moment and product of inertia matrix is given as

$$I_{jk} = \begin{bmatrix} I_{11} & I_{21} & I_{31} \\ I_{12} & I_{22} & I_{32} \\ I_{13} & I_{23} & I_{33} \end{bmatrix} + A_{mn} \quad (j = 1, 2, 3) \quad (m = 4, 5, 6)$$

where  $A_{mn}$  represents added mass coefficients, and the values within the brackets represent ship moment and products of inertia.

If we can evaluate the external forces ( $F_j$ ) and moments ( $T_j$ ) required by expressions (5) and (7), we can solve for the ship translational ( $V_G$ ) and rotational ( $\omega$ ) velocities. These, in turn, are used in equations (4) and (6) to yield the ship translational ( $X_G$ ) and rotational ( $\alpha$ ) displacements. The integration of these four first-order ordinary differential equations is performed numerically with the fourth-order Runge-Kutta scheme.

Thus, the prediction of ship motions by this method then becomes a matter of predicting the external forces and moments. The various types of forces and moments which comprise the total force and moment used in equations (5) and (7) are outlined in the following section.

## 2.2 EVALUATION OF EXTERNAL FORCES AND MOMENTS

The basic method used to evaluate the external forces will be based on strip theory. This approach is used to evaluate forces throughout the simulation of ship motions and loads. An additional and important feature is the prediction of pressures on the hull using a three-dimensional hull source representation. The resultant force on the ship from these pressures can be substituted for the hydrodynamic forces predicted from the strip approach into the equations of motion for a selected interval of time. The interval of time for which this force substitution may be made must be limited in order to minimize the considerable computing effort associated with a three-dimensional solution in the time domain. Figure 2 depicts this procedure. It should be emphasized that the formulations for the two methods (strip and three-dimensional) are separate and distinct and each can provide force information for the solution of the equations of motion.

A brief outline of the force components that comprise the total force used in the ship motion equations follows. We first examine the strip method followed by a brief discussion of the three-dimensional method.

### 2.2.1 Strip Approach Forces

Following strip theory, we will assume that the hydrodynamic force acting on the ship can be decomposed into three parts:

- (a) Froude-Krylov Force - The resultant force from the pressure in the waves which acts on the hull surface with the assumption that the pressure field is not affected by the presence of the ship.
- (b) Diffraction Force - A correction to the Froude-Krylov force that accounts for the disturbance of the ambient wave field by the presence of the ship.

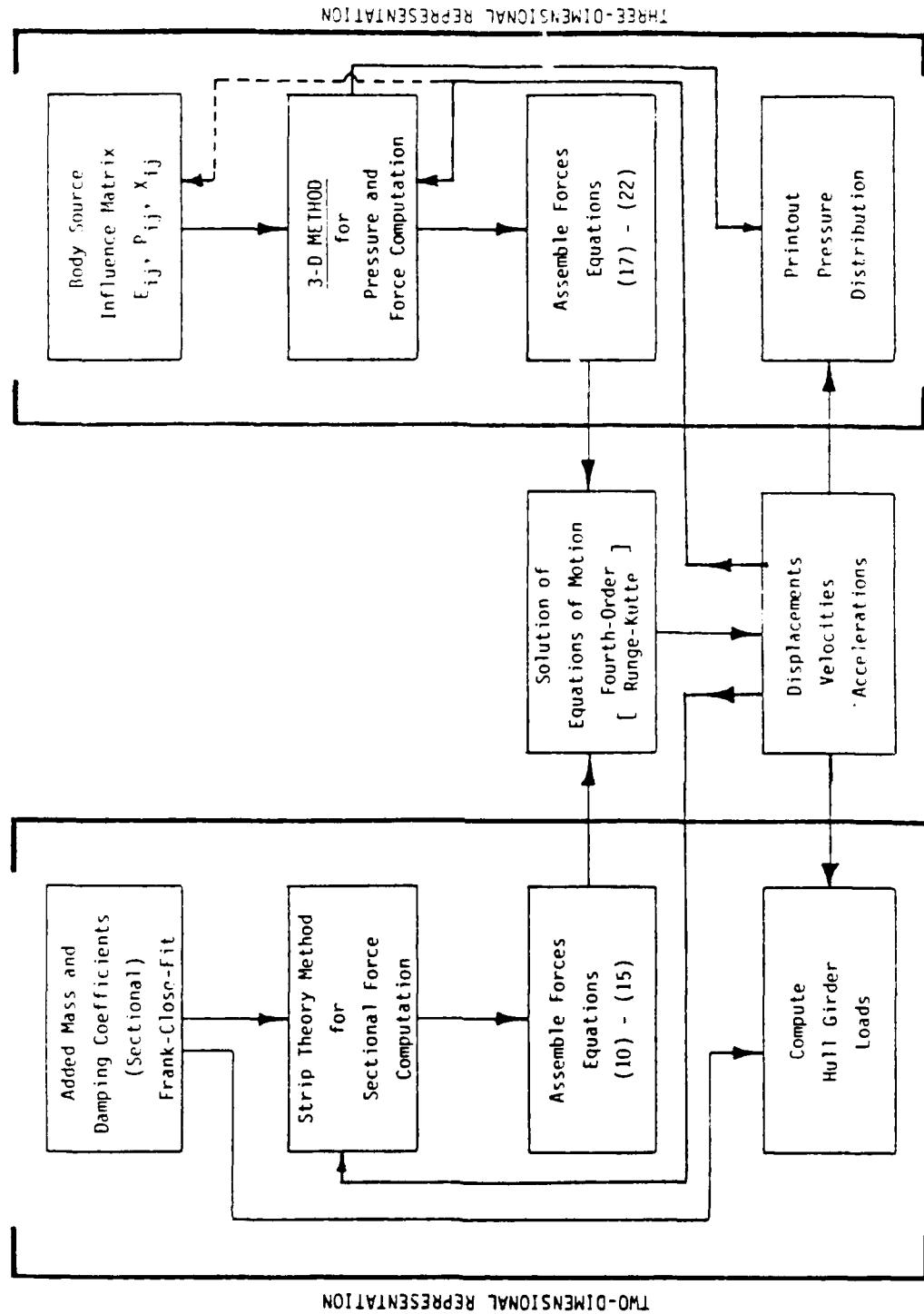


Figure 2 Diagram of Computational Scheme

- (c) Ship Motion-Induced Force - The force resulting from the motion of the ship with the assumption that it undergoes this motion in calm water.

The evaluation of the Froude-Krylov forces is obtained by integrating the pressure existing in the undisturbed waves over the wetted surface of the hull. The evaluation of the diffraction force and ship motion-induced force will generally be according to the elementary strip theory (see Raff [4]). Linear wave theory is employed and it will be assumed that the Froude-Krylov pressure and diffraction force evaluated in an irregular wave system is equivalent to the summation of the pressures and forces from the individual waves that comprise the irregular system.

The calculation of added mass and damping coefficients used in the evaluation of diffraction and ship motion-induced forces is by the Frank close-fit method. Because these coefficients are frequency dependent, a problem exists as to which frequency to use in the ship motion-induced force calculations since the ship motion may be irregular (non-harmonic). One approach taken by several investigators [26, 27] is to select a constant set of coefficients associated with one frequency.

We propose two other approaches and briefly examine the effect of each in Section 3.3. The first and simpler method is for a user-specified fixed value associated with the highest peak of the response spectra obtained from a frequency domain analysis or sea spectrum. The second approach is based on a scheme that samples the previous two zero-crossing periods of motion in sway, heave and roll. The two values are averaged, and three characteristic frequencies are derived for evaluation of the sectional hydrodynamic coefficients. The sway-roll or roll-sway coefficients are (arbitrarily) linked to the sway characteristic frequency.

In frequency domain strip theory formulations, the added mass and damping coefficients are evaluated at the still waterline. In the present formulation, at each time step, two-dimensional hydrodynamic coefficients can be evaluated for each section at either the mean still water draft or at the instantaneous depth of immersion. When it is desired that the hydrodynamic coefficients be draft dependent, the coefficients are obtained by linear interpolation from an array of six values corresponding to six drafts covering a range from near the baseline to the deck edge. Since the hydrodynamic coefficients are also frequency dependent, they are selected using linear interpolation from an array of twelve values associated with a range of twelve frequencies specified by the user. Thus, when the two-dimensional sectional coefficients are to be both draft and frequency dependent, two-dimensional linear interpolation is performed.

One of the advantages of the time domain approach is that it provides the capability to predict the ship motion and loads response to virtually any force for which there is an evaluation method. The force may be an arbitrary function of space and time, or a function of absolute or relative ship position or velocity. Assuming there is an acceptable method of predicting the associated force and moment, we could incorporate into the present method such

phenomena as bottom slamming, flare slamming, and the shipping of green water; as well as wind forces, mooring forces, rudder and propeller forces, viscous and appendage related damping, etc. The incorporation of methods to evaluate most of these forces will be left as the subject of subsequent investigations. We will, however, include here a flare force prediction method and also the means to incorporate a quadratic damping force. For flare impact force, we will use the approach described by Meyerhoff [26].

### 2.2.2 Three-Dimensional Pressure and Forces

The ship hull is modeled by quadrilateral panels. At the center of each panel, the pressure is evaluated, and resultant forces may be obtained. The pressure computed by this method includes the Froude-Krylov pressure (excluding the hydrostatic part), the diffraction pressure and the ship motion-induced pressure. Further description of this method will be left to Section 2.5, where it is discussed in detail.

### 2.2.3 Total Force Equations

The total force equations are given using the notation shown below. The force for each degree of freedom is indicated by:

X = longitudinal force  
Y = vertical force  
Z = lateral force  
K = roll moment  
N = yaw moment  
M = pitch moment

Subscripts to these force symbols specify the type of force according to:

b = Froude-Krylov  
h = ship motion-induced  
w = wave diffraction  
f = "flare" force  
q = quadratic damping force  
t = total force

Two sets of equations will be given; the first showing the force components normally used during the simulation, and the second showing the force components when the three-dimensional method is invoked. The external forces (F) and moments (M) used in the equations of motion (5) and (7) can be assembled from various sectional force components according to:

$$F_1 = \int \frac{X_b}{dx} dx \quad (10)$$

$$F_2 = \int \frac{dY_h}{dx} dx + \int \frac{dY_w}{dx} + \int \frac{dY_f}{dx} dx + \int \frac{dY_b}{dx} dx + Y_q \quad (11)$$

$$F_3 = \int \frac{dZ_h}{dx} dx + \int \frac{dZ_w}{dx} dx + \int \frac{dZ_b}{dx} dx + Z_q \quad (12)$$

$$T_1 = \int \frac{dK_h}{dx} dx + \int \frac{dK_w}{dx} dx + \int \frac{dK_b}{dx} dx + K_q \quad (13)$$

$$T_2 = \int x \frac{dZ_h}{dx} dx + \int x \frac{dZ_w}{dx} dx + \int \frac{dN_b}{dx} dx + N_q \quad (14)$$

$$T_3 = \int x \frac{dY_h}{dx} dx + \int x \frac{dY_w}{dx} dx + \int x \frac{dY_f}{dx} dx + \int \frac{dM_b}{dx} dx + M_q \quad (15)$$

All integrations are performed over the length of the ship. The strip theory equations used to evaluate the sectional forces are given in Section 2.4. As will be seen in that section, in the equations for the sectional ship motion-induced forces there is a part related to acceleration. These acceleration-related forces cannot be computed directly at any particular time step, since the acceleration values at that time are not a priori known. Consequently, the acceleration force terms in those equations are extracted and transferred to the mass moment and product of inertia matrices as the second terms in the right-hand side of expressions (8) and (9) given earlier. These matrices are assembled according to the following expressions:

$$A_{22} = \int a_{22} dx$$

$$A_{33} = \int a_{33} dx$$

$$A_{43} = \int a_{34} dx$$

$$A_{44} = \int a_{44} dx \quad (16)$$

$$A_{45} = \int x a_{34} dx$$

$$A_{53} = \int x a_{33} dx$$

$$A_{55} = \int x^2 a_{33} dx$$

$$A_{62} = \int x a_{22} dx$$

$$A_{66} = \int x^2 a_{22} dx$$

with the remaining values of  $A_{jk} = 0$ . All integrations are over the length of the ship.

When the three-dimensional pressure calculational procedure is run concurrently with the stripwise force calculations, three-dimensional pressure forces may be substituted for the stripwise hydrodynamic forces. During such an interval, the force expressions (10) - (15) would instead appear as:

$$x_T = x_{3D} + x_b^s + x_q \quad (17)$$

$$y_T = y_{3D} + y_b^s + \int \frac{dy_f}{dx} dx + y_q \quad (18)$$

$$z_T = z_{3D} + z_b^s + y_q \quad (19)$$

$$k_T = k_{3D} + k_b^s + k_q \quad (20)$$

$$n_T = n_{3D} + n_b^s + n_q \quad (21)$$

$$m_T = m_{3D} + m_b^s + \int x \frac{dy_f}{dx} dx + m_q \quad (22)$$

where  $x_b^s \dots m_b^s$  are the hydrostatic force components of the Froude-Krylov forces, and  $x_{3D} \dots m_{3D}$  are the force components calculated from the three-dimensional pressure computations.

This completes the formulation of the equations of motion and the force equations. The next several sections will present the computation of the Froude-Krylov force, the sectional diffraction and ship motion-induced forces, the flare impact force, and the three-dimensional pressures and resultant forces.

### 2.3 FROUDE-KRYLOV FORCES

We will assume that the elevation of the sea surface  $\eta(\vec{x}, t)$  can be described as the superposition of a number of sinusoids of the form:

$$\eta(\vec{x}, t) = \sum_{i=1}^N a_i \cos(k_i \vec{x} - \omega_i t + \epsilon_i) = \sum_{i=1}^N \eta_i \quad (23)$$

The expression for hydrostatic and dynamic pressure can be derived from Bernoulli's equation and the definition of velocity potential for the incident wave field. If we include only the linear terms, and consider only deep water, the expression for pressure may be given as

$$p(t, x, y, z) = -\rho g [y - \sum_{i=1}^N e^{k_i y} \eta_i] \quad (24)$$

The Froude-Krylov force may be obtained by integrating the pressure over the immersed surface of the ship. This surface integral may be replaced by a volume integral,\* so that the expressions for total Froude-Krylov forces and moments can be given by the integral of the pressure gradients. Sectional forces can be evaluated according to:

$$\frac{dx_b}{dx} = - \iint \frac{\partial p}{\partial x} dy dz$$

---

\* Gauss Theorem -

$$\mathbf{F} = \iint \mathbf{n} p dA = \iiint \nabla p dV$$

$$\begin{aligned}
 \frac{dy_b}{dx} &= - \iint \frac{\partial p}{\partial y} dy dz \\
 \frac{dz_b}{dx} &= - \iint \frac{\partial p}{\partial z} dy dz \\
 \frac{dk_b}{dx} &= \iint (z \frac{\partial p}{\partial y} - y \frac{\partial p}{\partial z}) dy dz \\
 \frac{dn_b}{dx} &= \iint (x \frac{\partial p}{\partial z} - z \frac{\partial p}{\partial x}) dy dz \\
 \frac{dm_b}{dx} &= \iint (y \frac{\partial p}{\partial x} - x \frac{\partial p}{\partial y}) dy dz
 \end{aligned} \tag{25}$$

For each section, vertical integration extends to the wave surface rather than the mean water level. This fact necessitates some sort of approximation to evaluate pressures in the free surface zone since linear wave theory implies infinitesimal amplitudes which do not extend measurably above or below the mean water level.

From a review of the relevant literature, there appear to be three basic approaches for approximating the velocities and pressures in the free surface zone:

- (a) Unmodified Formula - Use the same formulas (for pressure) above mean sea level that apply below sea level. (Eq. 26 with no restrictions on  $y$ .)
- (b) Stretching Correction - Stretch the still water level in the formula to the sea surface.
- (c) Hydrostatic - Assume the pressure in the wave above the mean water level is hydrostatic.

There is not sufficient experimental data to support the use of one scheme over the next. The CAPSIZE program [29] uses the unmodified formula. There are also some limited experimental data obtained by Chakrabarti [30] to indicate that a hydrostatic pressure assumption is accurate in regular waves. If we select the hydrostatic assumption, the pressure equation may then be written as

$$p(t, x, y, z) = -\rho g \left[ y - \sum_{i=1}^N e^{k_i y} n_i \right] \quad y < 0 \tag{26}$$

$$p(t, x, y, z) = -\rho g \left( y - \sum_{i=1}^N n_i \right) \quad y > 0 \quad (27)$$

The differences in ship response as a result of using the unmodified pressure formula above the mean waterline were investigated. Comparisons for heave and pitch response of the SL-7 containership in 15-foot waves indicated that the differences were negligible. In any event, both methods are approximations. Their use, however, is necessitated by the employment of linear wave theory, and we therefore cannot escape the use of such simplifications. The computer code, as presently written, allows the user to select either approximation.

## 2.4 SECTIONAL HYDRODYNAMIC FORCES

Following elementary strip theory, local sectional hydrodynamic forces induced by the ship's motion and by diffraction force for heave, sway and roll are given in this section. The equations given below are equivalent to the basic equations given by Raff [4] in SSC-230. Flare impact force and quadratic roll damping are also discussed.

### Vertical Sectional Ship Motion-Induced Force

$$\begin{aligned} \frac{dy_h}{dx} &= -a_{22} (\ddot{y}_G + x\dot{\psi} - 2U\dot{\psi}) \\ &\quad - b_{22} (\dot{y}_G + x\dot{\psi} - U\dot{\psi}) \\ &\quad + U \frac{da_{22}}{dx} (\dot{y}_G + x\dot{\psi} - U\dot{\psi}) \end{aligned} \quad (28)$$

### Vertical Sectional Diffraction Force

$$\frac{dy_w}{dx} = \sum_{i=1}^N [\xi_i \dot{a}_{22} + r_i (b_{22} - U \frac{da_{22}}{dx})] \quad (29)$$

### Lateral Sectional Ship Motion-Induced Force

$$\begin{aligned}
 \frac{dZ_h}{dx} = & - a_{33} (\ddot{z} - \dot{x}\ddot{\phi} + 2U\dot{\phi}) \\
 & + (U \frac{da_{33}}{dx} - b_{33}) (\dot{z} - x\dot{\phi} + U\phi) \\
 & + (a_{43} + h_{cg} a_{33}) \ddot{\theta} \\
 & + [b_{43} + h_{cg} b_{33} - U (\frac{da_{43}}{dx} + h_{cg} \frac{da_{33}}{dx})] \dot{\theta}
 \end{aligned} \tag{30}$$

### Lateral Sectional Diffraction Force

$$\begin{aligned}
 \frac{dZ_w}{dx} = & \sum_{i=1}^N \left\{ [\dot{\zeta}_i a_{33} - \zeta_i (U \frac{da_{33}}{dx} - b_{33})] \right. \\
 & \left. - [\dot{\kappa}_i h_{cg} a_{34} - \kappa_i h_{cg} (U \frac{da_{34}}{dx} - b_{34})] \right\}
 \end{aligned} \tag{31}$$

### Roll Sectional Ship Motion-Induced Moment

$$\begin{aligned}
 \frac{dK_h}{dx} = & - (a_{44} + h_{cg} a_{34}) \ddot{\theta} \\
 & - [b_{44} + h_{cg} b_{34} - U (\frac{da_{44}}{dx} + h_{cg} \frac{da_{34}}{dx})] \dot{\theta} \\
 & + a_{34} (\ddot{z} - \dot{x}\ddot{\phi} + 2U\dot{\phi}) \\
 & + (b_{34} - U \frac{da_{34}}{dx}) (\dot{z} - x\dot{\phi} + U\phi) - h_{cg} \frac{dZ_h}{dx}
 \end{aligned} \tag{32}$$

### Roll Sectional Diffraction Force

$$\frac{dK_w}{dx} = \sum_{i=1}^N \left\{ \dot{\kappa}_i a_{44} - \kappa_i \left( U \frac{da_{44}}{dx} - b_{44} \right) \right. \\ \left. - [\dot{\zeta}_i h_{cg} a_{34} - \zeta_i \left( U \frac{da_{34}}{dx} + b_{34} \right)] \right\} - h_{cg} \frac{dz_w}{dx}. \quad (33)$$

Following the procedure used in the program CAPSIZE [29], each ship section is defined as a closed polygon made up of straight line segments between offsets. The integrals of vertical, horizontal and "roll" wave velocities and accelerations, as well as pressure gradients over each section, are evaluated exactly at each time step. Longitudinal integrations of sectional diffraction forces and Froude-Krylov forces (excluding hydrostatic component) are performed assuming the sectional forces are functions of the following form:

$$f(x) = \sum_{i=1}^N [C_i \cos(k_i' x) + S_i \sin(k_i' x)]$$

where

$S_i, C_i$  = sine and cosine components of force fluctuation for wave component  $i$ , the relative magnitudes of which provide the proper phase relationship of all wave-related forces.

$k_i'$  = projection of the wave number onto the  $x$ -axis of ship.

Longitudinal integrations are performed assuming  $C_i$  and  $S_i$  vary linearly along the ship's length.

### Flare Force

The approach for evaluating flare force is actually an extension of the strip theory expressions. Its incorporation into the present methodology serves to highlight the capability of the time domain method to account for the effects of the above-waterline hull on motions and loads. Furthermore, earlier work by Kaplan [31], Borreson and Tellsgaard [27], and Meyerhoff [22] have already provided the basic method to compute flare forces.

Following the approach described by Meyerhoff, the time derivative of the relative wave elevation for any strip may be given as

$$\dot{\eta}_r = \frac{\omega_0}{\omega_e} \dot{\eta} - \dot{y}_G - \dot{x}\psi + \psi U \quad (34)$$

where  $\dot{\eta}$  denotes the time-derivative of the wave elevation relative to the ship-fixed coordinate system,  $\omega_0$  is wave frequency and  $\omega_e$  is frequency of encounter. The convective derivative of relative velocity is accounted for by the factor  $\omega_0 / \omega_e$ . In the derivation of the expression for hydrodynamic inertia forces in the strip method, it can be shown that a nonlinear term results which represents an impact term. It contains the square of the relative velocity, and according to Meyerhoff [26] appears as:

$$\frac{dy_f}{dx} = \mu (\dot{\eta}_r)^2$$

where

$$\begin{aligned} \mu &= \left\{ \frac{\partial a_{22}(\infty)}{\partial \dot{\eta}_r} \right\} && \text{if } \dot{\eta}_r > 0 \\ &= 0 && \text{if } \dot{\eta}_r < 0 \end{aligned}$$

The limiting value of added mass at infinite frequency is used in accordance with the theory of normal-symmetric impact upon a calm water surface. (It should also be pointed out that this formulation does not account for diffracted free surface motion, and the name "Froude-Krylov flare force" might more accurately represent the effect.)

#### Quadratic Damping

The expressions for total forces and moments (10) - (15) and (17) - (22) each contain a term which represents a force or moment which is proportional to velocity-squared. The user of the computer program may specify, as input, his own values for quadratic damping coefficients. Accurate roll prediction often requires some quadratic roll damping. The damping moment associated with roll, for example, may be written in the form

$$K_q = B_{44}^* |\dot{\theta}| \dot{\theta}$$

where  $B_{44}^*$  is the quadratic roll damping coefficient for the ship, and  $\dot{\theta}$  is roll angle velocity.

## 2.5 THREE-DIMENSIONAL DYNAMIC PRESSURES AND FORCES

### 2.5.1 Introduction

A numerical method for calculating the transient three-dimensional flow induced by the motion in waves of a floating body of arbitrary shape with forward speed is presented in this section. Dynamic pressures and the resultant forces and moments acting on the hull surface can be evaluated in the time domain using this technique. The solution is generated in terms of a source distribution representation of the body and a spectral representation of the free surface. The approach presented here expands upon the work of R.B. Chapman [5,6]. Although Chapman had provided the basic method to solve the problem of ship motions in waves, his formulation did not explicitly include the ambient wave field effects and associated diffraction flow.

Following Chapman, the general formulation is linearized, assuming that the individual potentials and their derivatives associated with forward speed, body motion, free surface disturbance caused by radiated and diffracted waves, and the ambient wave flow are each sufficiently small to ignore higher order terms and cross-products. The free surface equations are also linearized. The formulation partially accounts for the "exact" hull boundary by evaluating hydrodynamic pressures on the actual immersed portion of the body surface at each time step below the still waterline. Thus, the effect of large-amplitude motions is included to some extent.

It should be emphasized that this three-dimensional approach is a separate procedure quite distinct from the strip formulation and equations of motion solution techniques that form the basic framework. It is best viewed as a "parallel process," interfacing with the main solution procedures in the following ways:

- (a) It requires, as input, the specification of body position and velocities at each time step.
- (b) It provides as output forces and moments on the hull, as well as additional information regarding distributed dynamic pressures.

In the formulation that follows, for the convenience of the reader who wishes to refer to Chapman's work, we will use Chapman's coordinate system throughout Section 2.5.

### 2.5.2 Formulation

A Cartesian coordinate system is fixed in space with the x-axis in the direction of the ship's forward advance, positive forward; the z-axis positive

downward and  $y$ -axis positive to starboard. The still mean water level corresponds to  $z=0$ . The free surface elevation is specified by  $(x,y,t)$  and the ship's hull is defined by  $S(x,y,z,t) = 0$  for  $z > 0$ . If the fluid is assumed to be inviscid, incompressible and homogeneous and the flow irrotational, then the fluid velocity  $\vec{v}(x, t)$  can be represented by the gradient of the velocity potential  $\phi(x, t)$ . If we linearize the free surface equations, the velocity potential must satisfy the following conditions:

$$\nabla^2 \phi = 0 \quad z > 0 \quad (35)$$

$$\frac{\partial \phi}{\partial t} = -g n \quad z = 0 \quad (36)$$

$$\frac{\partial \phi}{\partial z} = \frac{\partial n}{\partial t} \quad z = 0 \quad (37)$$

$$\frac{\partial \phi}{\partial n} - \vec{V}_S \cdot \vec{n} = 0 \quad - \text{on } S(x, y, z, t) = 0 \quad (38)$$

where  $\vec{V}_S$  is the velocity at any point on the hull surface  $S$ , and  $\vec{n}$  is the unit normal to the boundary surface at the point, pointing outward. The velocity potential can be decomposed into two parts:

$$\phi(x, y, z, t) = [-Ux + \phi_S(x, y, z) + \phi_T(x, y, z, t)] \quad (39)$$

where  $-Ux + \phi_S$  is the steady part and  $U$  is the forward speed of the ship, and  $\phi_T(x, y, z, t)$  is the time-varying potential. In the present formulation, we will neglect the steady part and consider only the time-varying potential.

Separating the time-varying potential into three parts, we obtain

$$\phi_T = \phi_B + \phi_{FS} + \phi_A \quad (40)$$

where  $\phi_B$  represents the instantaneous effect of the body,  $\phi_{FS}$  represents the existing free surface disturbance due to previously radiated and diffracted waves, and  $\phi_A$  is the ambient wave potential.

The body potential will be represented by a distribution of simple sources over the wetted hull and its negative image. A spectral representation of the free surface potential will be used so that the diffracted and radiated wave fields are represented by two series, harmonic in space and time. The potential for the ambient wave system will be given according to linear theory for progressive waves. It should be noted that, although the method can be extended to include sources distributed over the entire body, the present procedure only distributes sources over the body below the mean waterline.

The objective of this analysis is to compute the hydrodynamic pressure on the hull, as determined from the potential field  $\phi_T(x,y,z,t)$ . The dynamic pressure can be obtained from Bernoulli's equation applied to  $\phi_T(x,y,z,t)$ . If the flow is assumed to be slow enough that the nonlinear term can be neglected, Bernoulli's equation is:

$$p_T = -\rho \frac{\partial \phi_T}{\partial t} = -\rho \frac{\partial}{\partial t} [\phi_B + \phi_{FS} + \phi_A] \quad (41)$$

By linearizing the problem, we can evaluate the total pressure at any time or point as the sum of the individual pressure components, as given by:

$$p_B(x,y,z,t) = -\rho \left[ \frac{\partial \phi_B}{\partial t} - \vec{V}_s \cdot \vec{\nabla} \phi_B \right] \quad (42)$$

$$p_{FS}(x,y,z,t) = -\rho \frac{\partial \phi_{FS}}{\partial t} \quad (43)$$

$$p_A(x,y,z,t) = -\rho \frac{\partial \phi_A}{\partial t} \quad (44)$$

The convective derivative for the body pressure expression is included because the Bernoulli equation given here is for fixed points in space, yet the body potential is associated with the moving hull surface. We will assume, however, that products of the body velocity and potential gradients are negligible with the exception of  $U \frac{\partial \phi_B}{\partial x}$ . Equation (42) then becomes:

$$p_B(x, y, z, t) = -\rho \left[ \frac{\partial \phi_B}{\partial t} - U \frac{\partial \phi_B}{\partial x} \right]. \quad (45)$$

Prior to describing the individual potential representations in detail, it will be advantageous to first describe the numerical solution procedure on a step-by-step basis.

### 2.5.3 Solution Procedure

This is an initial value problem that ideally should start from a condition at rest. Prior to starting the simulation, the following arrays relating to the body source representation are calculated:

- (a)  $E_{ij}$  - gives the normal velocity component at the center point of panel i induced by a uniform source distributed over panel j and its image. (As will be explained, the hull surface is modeled by quadrilateral panels; at the center of each is a simple source.)
- (b)  $\hat{P}_{ij}$  - gives the potential at the center of panel i induced by uniform source density of unit strength acting over panel j.
- (c)  $x_{ij}$  - gives the x-direction velocity component at the center point of panel i induced by a uniform source distributed over panel j and its image.

The simulation progresses by a series of small time steps, according to the following sequence:

#### Step 1.

As we begin each time step, we will have already computed the velocities, accelerations and pressures induced by the free-surface disturbance and ambient wave field at the center of each panel. (These will be known from steps (5) and (6) of the previous time cycle.) The body velocity and acceleration will have been obtained from the solution to the equations of motion.

First, for time  $t = t_n$ , compute the resultant total normal velocity ( $\vec{v}_T \cdot \vec{n}$ ) \* at the center of each panel.\* This resultant velocity represents the sum of the velocity from the body motion, the velocity induced by the existing free surface disturbance, and the velocity induced by the ambient wave field:

$$\vec{v}_T \cdot \vec{n} = (\vec{v}_B + \vec{v}_{FS} + \vec{v}_A) \cdot \vec{n} \text{ at panel centers.} \quad (46)$$

According to Chapman [6], it is more convenient to use accelerations instead of velocities. Equation (46) can then be expressed as:

$$\vec{a}_T \cdot \vec{n} = (\vec{a}_B + \vec{a}_{FS} - U \frac{\partial}{\partial x} \vec{v}_{FS} + \vec{a}_A - U \frac{\partial}{\partial x} \vec{v}_A) \cdot \vec{n}. \quad (47)$$

(The convective derivatives are required in this case for  $\vec{a}_{FS}$  and  $\vec{a}_I$  because we are in a hull-fixed system when computing the resultant normal acceleration on the body.)

### Step 2.

Knowing  $\vec{a}_T$  from step (1) and having precalculated  $E_{ij}$ , determine the time derivative of the source strengths  $\dot{\sigma}_j$  according to

$$\sum_{i=1}^{N_B} E_{ij} \dot{\sigma}_j = \vec{a}_T \cdot \vec{n} \quad \text{at } t = t_n. \quad (48)$$

### Step 3.

Calculate the body-induced component of pressure at the center point of each panel induced by the computed time derivative of the source strength in a hull fixed system according to

\* In the equations that follow, it is understood that all normal vectors, areas, positions or coordinates on the hull are functions of time, even though they may not be so specified.

$$p_B = -\rho \frac{\partial \phi_B}{\partial t} + \rho U \frac{\partial \phi_B}{\partial x} \quad (49)$$

or

$$p_B = -\rho \sum_{j=1}^{N_B} \hat{P}_{ij} \dot{\sigma}_j(t_n) + \rho U X_{ij} \sigma_j(t_n) \quad (50)$$

#### Step 4.

Compute total pressure at each panel

$$p_T(t_n) = p_B(t_n) + p_{FS}(t_n) + p_A(t_n).$$

#### Step 5.

Update the source strengths for this time step ( $t_n$ ) according to

$$\sigma_i(t_n) \approx \sigma_i(t_n - \Delta t) + \Delta t \dot{\sigma}_i(t_n) \quad (51)$$

#### Step 6.

As described in Section 2.5.5, update the free surface representations. Modify the free surface to account for the effect of the hull source strengths on the free surface. Calculate acceleration induced by the free surface at the center of each panel  $\dot{a}_{FS}(t_n + \Delta t)$  and the pressure induced by the free surface disturbance at the center of each panel  $p_{FS}(t_n + \Delta t)$ .

#### Step 7.

Update the ambient wave field. Calculate the acceleration  $\dot{a}_A(t_n + \Delta t)$  and pressure  $p_A(t_n + \Delta t)$  induced by the ambient wave field at the center of each panel.

Step 8.

Go to Step 1 with the new  $\vec{a}_{FS}$ ,  $\vec{a}_A$  and newly prescribed  $\vec{a}_B$ .

2.5.4 Body Representation

As shown in Figure 3, the hull is modeled by a set of  $N_B$  quadrilateral panels. A simple source and its image is distributed over each panel. The expression for the body potential can then be expressed as:

$$\phi_B(x, y, z) = \sum_{i=1}^{N_B} \sigma_i \iint_{S_i} G(x, y, z, x', y', z') dS' \quad (53)$$

in which

$$G(x, y, z, x', y', z') = \frac{[(x-x')^2 + (y-y')^2 + (z-z')^2]^{-1/2}}{[(x-x')^2 + (y-y')^2 + (z+z')^2]^{-1/2}} \quad (54)$$

$\sigma_i$  is the strength on the  $i^{th}$  source panel

$S_i$  is the  $i^{th}$  panel surface.

Panel source strengths are evaluated at each time step using a linear system of equations relating resulting total normal velocities ( $\vec{v}_T \cdot \vec{n}$ ) at each panel center to the source strength  $\sigma_j$  at every other panel center and by the satisfaction of the hull boundary condition at the center of each panel. The exact method of Hess and Smith [32] is used here to determine the normal velocity component at the center point of panel  $i$  induced by a plane quadrilateral source element with a unit value of source density at the center point of panel  $j$ . A body coefficient scalar matrix  $E_{ij}$  is thus computed which can be used to determine unknown source densities when given panel center normal velocities, according to

$$\vec{v}_T \cdot \vec{n}_i = \sum_{j=1}^{N_B} E_{ij} \sigma_j \quad (55)$$

As was shown in equation (46), the panel center total normal velocity is the sum of components from the hull motion and induced velocities from radiated and diffracted free surface disturbances and ambient wave field.

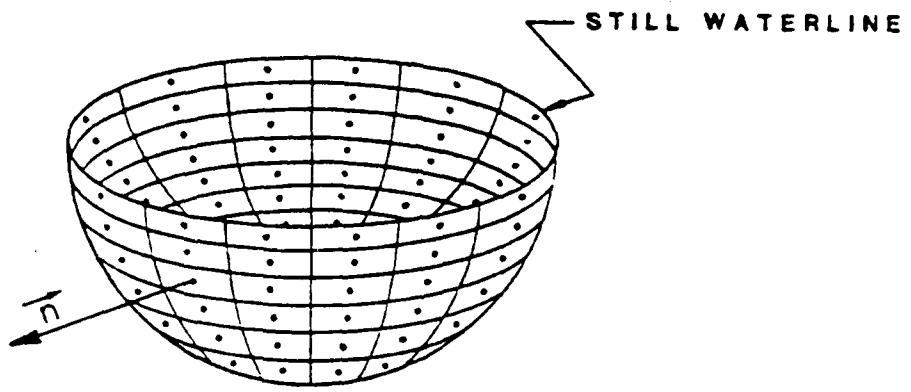


Figure 3 Quadrilateral panels and source representation of semisubmerged sphere.

Also, in Step 3 of the computational sequence, equations (49) and (50) show that the calculation of body-induced pressure at panel centers requires the use of two other arrays  $\hat{P}_{ij}$  and  $X_{ij}$ . The  $X_{ij}$  array gives the  $x$ -direction velocity component at the center point of panel  $i$  induced by a uniform source (of unit strength) distributed over panel  $j$  and its image. It is thus very similar to the  $E_{ij}$  array, relating the  $x$ -component instead of the normal component of panel velocities. In practice, it is evaluated directly from the information used to evaluate  $E_{ij}$ .

The  $\hat{P}_{ij}$  array gives the potential at the center of panel  $i$  induced by a uniform source (of unit strength) distributed over panel  $j$  and its image, or

$$\varphi_{B_i} = \sum_{j=1}^{N_B} \hat{P}_{ij} \sigma_j \quad (56)$$

Looking back at equation (53) for a moment, it can be seen the  $\hat{P}_{ij}$  can be computed by relating each panel center to every other panel center using the expression for  $G(x, y, z, x', y', z')$ , or in the indexed notation,

$$\begin{aligned} \hat{P}_{ij} = & \iint_{S_i} dS_i \{ [(x_j - x_i)^2 + (y_j - y_i)^2 + (z_j - z_i)^2]^{-1/2} \\ & - [(x_j + x_i)^2 + (y_j - y_i)^2 + (z_j + z_i)^2]^{-1/2} \} \end{aligned} \quad (57)$$

These integrals are evaluated numerically by dividing the surface  $S_i$  into many small elements and evaluating the above integrand at the center of each smaller element.

### 2.5.5 Free Surface Representation

A spectral representation of the free surface will be used. Let the free surface elevation and velocity potential be represented by  $n(x, y, t)$  and  $\varphi_{FS}(x, y, z, t)$ , respectively. The elevation and potential satisfy the dynamic and kinematic linearized free-surface conditions at  $z = 0$ .

$$\frac{\partial}{\partial t} \varphi(x, y, 0, t) = -g n(x, y, t) \quad (58)$$

$$\frac{\partial \phi}{\partial z} n(x,y,t) = -\frac{\partial \eta}{\partial t} (x,y,o,t) \quad (59)$$

Now assume that both the elevation and deep water potential can be represented by the real part of a finite summation of harmonics in the following forms:

$$n(x,y,t) = \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m [A_{nm}(t) e^{i(kx_n \cdot x + ky_m \cdot y)} + A_{nm}^*(t) e^{i(kx_n \cdot x - ky_m \cdot y)}] \quad (60)$$

$$\phi_{FS}(x,y,z,t) = \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m [B_{nm}(t) \omega_{nm} k_{nm}^{-1} e^{i(kx_n \cdot x + ky_m \cdot y)} + B_{nm}^*(t) \omega_{nm} k_{nm}^{-1} e^{i(kx_n \cdot x - ky_m \cdot y)}] e^{-k_{nm} \cdot z} \quad (61)$$

where

$A_{nm}, B_{nm}$  - complex functions of wave numbers and time  
(to be further defined below)

$A_{nm}^*, B_{nm}^*$  - complex conjugates

$kx_n, ky_m$  - wave numbers in x and y; e.g.,  $\frac{\omega_n^2}{g}$

$\Delta kx_n, \Delta ky_m$  - wave number spacing; e.g.,  $\Delta kx_n = kx_{n+1} - kx_n$

$k_{nm}$  -  $k_{nm}^2 = kx_n^2 + ky_m^2$

$\omega_{nm}$  -  $\omega_{nm}^2 = g [kx_n^2 + ky_m^2]^{1/2}$

Substitution of equations (60) and (61) into the free surface equations (58) and (59) would confirm that the above elevation and potential expressions do indeed satisfy the linearized free surface conditions. We would also obtain, from those substitutions, the following relationships between the complex amplitude functions:

$$\frac{d}{dt} A_{nm}(t) = \omega_{nm} B_{nm}(t) \quad (62)$$

$$\frac{d}{dt} B_{nm}(t) = -\omega_{nm} A_{nm}(t) \quad (63)$$

(The complex conjugates are described by identical expressions).

As part of the free surface elevation representation, we further define the complex amplitude function  $A_{nm}$  as

$$A_{nm}(t) = a_{nm} \cos \omega_{nm} t + b_{nm} \sin \omega_{nm} t \quad (64)$$

where  $a_{nm}$  and  $b_{nm}$  are complex constants. Substitution of (64) into (62) yields the expression for  $B_{nm}(t)$ .

$$B_{nm}(t) = b_{nm} \cos \omega_{nm} t - a_{nm} \sin \omega_{nm} t \quad (65)$$

Similar expressions also describe the complex conjugates.

#### Updating the Free Surface

Equations (62), (63), (64) and (65) allow us to develop the expressions for the time evolution of  $A_{nm}(t)$  and  $B_{nm}(t)$ . Consider  $A_{nm}(t)$  first. If we increment the time in equation (64) by  $\Delta t$ , we obtain

$$A_{nm}(t + \Delta t) = a_{nm} \cos \omega_{nm} (t + \Delta t) + b_{nm} \sin \omega_{nm} (t + \Delta t) \quad (66)$$

Using the following trigonometric identities,

$$\cos(x \pm y) = \cos x \cos y \mp \sin x \sin y \quad (67)$$

$$\sin(x \pm y) = \sin x \cos y \pm \cos x \sin y$$

we can rewrite (66) as

$$\begin{aligned} A_{nm}(t + \Delta t) &= a_{nm} \cos \omega_{nm} t \cos \omega_{nm}(\Delta t) - a_{nm} \sin \omega_{nm} t \sin \omega_{nm}(\Delta t) \\ &\quad + b_{nm} \sin \omega_{nm} t \cos \omega_{nm}(\Delta t) + b_{nm} \cos \omega_{nm} t \sin \omega_{nm}(\Delta t) \end{aligned} \quad (68)$$

Rearranging (68), we can write

$$\begin{aligned} A_{nm}(t + \Delta t) &= [a_{nm} \cos \omega_{nm} t + b_{nm} \sin \omega_{nm} t] \cos \omega_{nm}(\Delta t) \\ &\quad + [b_{nm} \cos \omega_{nm} t - a_{nm} \sin \omega_{nm} t] \sin \omega_{nm}(\Delta t) \end{aligned} \quad (69)$$

It can be seen that the quantities in the brackets are equivalent to the right-hand sides of equations (64) and (65), so that we can now obtain

$$A_{nm}(t + \Delta t) = A_{nm}(t) \cos \omega_{nm}(\Delta t) + B_{nm}(t) \sin \omega_{nm}(\Delta t) \quad (70)$$

The expression for  $B_{nm}(t)$  can be similarly obtained and is given as

$$B_{nm}(t + \Delta t) = B_{nm}(t) \cos \omega_{nm}(\Delta t) - A_{nm}(t) \sin \omega_{nm}(\Delta t) \quad (71)$$

Identical expressions are used for updating  $A_{nm}^*(t)$  and  $B_{nm}^*(t)$ . Thus, expressions (70) and (71) provide the means to update the coefficients which define the wave field. To these updated values must be added any contribution to the wave field from the body motion between times  $t$  and  $t + \Delta t$ , as described next.

### Body Effect on the Free Surface

Next we consider the effect of the body source distribution on the wave elevation field over the time interval  $\Delta t$ . Assume that the change in  $A_{nm}(t)$  induced by the body between  $t_n$  and  $t_n + \Delta t$  is expressed by the sum of the effects of the individual sources and their images. For convenience, we will first replace a uniform source density acting over a panel of area  $A_i$  by a single point source with strength

$$s_i(t) = A_i [\sigma_i(t_n) + (t-t_n) \dot{\sigma}(t_n)] \quad (72)$$

which is located at the panel center. The time,  $t$ , is defined to be  $t = t_n + 1/2\Delta t$ , the midpoint of the time interval.

At any given point on the mean water level plane  $(x, y, 0)$ , the vertical velocity induced by the source points and their images is given by

$$\frac{\partial \phi_B(t)}{\partial z} = - \sum_{i=1}^{N_B} \frac{2z_i s_i(t)}{[(x-x_i)^2 + (y-y_i)^2 + z_i^2]^{3/2}} \quad (73)$$

According to Chapman [6], equation (73) can also be expressed in an integral form given as

$$\begin{aligned} \frac{\partial \phi_B(t)}{\partial z} &= \frac{2}{\pi} \sum_{i=1}^{N_B} s_i(t) \int_0^\infty dkx e^{ikx(x-x_i)} \int_{-\infty}^\infty dky \cos ky(y-y_i) \\ &\quad \cdot e^{-(kx^2 + ky^2)z_i} \end{aligned} \quad (74)$$

Substituting (74) into the linearized kinematic free surface condition (59), and integrating over the time interval  $\Delta t$ , we can rewrite (74) to show how the elevation changes over  $\Delta t$  due to the body,

$$\Delta n_B(x, y) = \frac{2}{\pi} \int_{t_n}^{t_n + \Delta t} \sum_{i=1}^{N_B} s_i(t) \int_0^{\infty} dkx e^{ikx(x-x_i)} \int_{-\infty}^{\infty} dky \cos ky(y-y_i) \\ \cdot e^{-(kx^2 + ky^2)/2} z_i \quad (75)$$

We may also write  $\Delta n_B(x, y)$  in a different form, following the same form of the original expression (60) defining the free surface elevation. In that form, we can write

$$\Delta n_B(x, y) = \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m [ \Delta A_{nm}^{BODY}(t) e^{i(kx_n \cdot x + ky_m \cdot y)} \\ + \Delta A_{nm}^{BODY*}(t) e^{-i(kx_n \cdot x - ky_m \cdot y)} ] \quad (76)$$

Then, if we represent the wave number integrals in (75) numerically by a finite summation, and also evaluate the time integral, it should be evident by direct comparison with (76) that the  $A_{nm}$  coefficient increments can be written as

$$\Delta A_{nm}^{BODY} = 2 \frac{\Delta t}{\pi} \sum_{i=1}^{N_B} s_i(t_n + 1/2 \Delta t) e^{-i(kx_n \cdot x_i + ky_m \cdot y_i)} e^{-k_{nm} z_i} \quad (77)$$

$$\Delta A_{nm}^{BODY*} = 2 \frac{\Delta t}{\pi} \sum_{i=1}^{N_B} s_i(t_n + 1/2 \Delta t) e^{-i(ky_n \cdot x_i - ky_m \cdot y_i)} e^{-k_{nm} z_i} \quad (78)$$

The changes in  $B_{nm}$  induced by the body can be derived from (78) and (79) using the relationship between  $A_{nm}(t)$  and  $B_{nm}(t)$  given in (63). Multiplying both sides of (63) by  $\Delta t$  and then integrating both sides over time, we obtain

$$\Delta B_{nm}^{BODY} = -1/2 \frac{\partial}{\partial t} A^{BODY}(t) \omega_{nm}(\Delta t)^2 \quad (79)$$

or

$$\Delta B_{nm}^{\text{BODY}} = -\frac{(\Delta t)^2}{\pi} \sum_{i=1}^{N_B} s_i(t_n) e^{-i(kx_n \cdot x_i + ky_m \cdot y_i)} e^{-k_{nm} z_i} \omega_{nm} \quad (80)$$

with a similar expression for  $\Delta B_{nm}^{\text{BODY}*}$ .

The effect of the body on the free surface can now be easily included by adding  $\Delta A_{nm}^{\text{BODY}}$ ,  $\Delta A_{nm}^{\text{BODY}*}$ ,  $\Delta B_{nm}^{\text{BODY}}$ , and  $\Delta B_{nm}^{\text{BODY}*}$  to the time evolution equations given earlier as (70) and (71) and the corresponding (complex conjugate) expressions.

#### Free Surface-Induced Pressure and Acceleration

Finally, we need to evaluate the pressure and acceleration induced by the free surface disturbance at the center of each panel. These two quantities are required in steps (4) and (1), respectively, of the simulation procedure. The pressure at any point  $(x, y, z)$  is given by

$$\begin{aligned} p_{FS} &= -\rho \frac{\partial \phi_{FS}}{\partial t} \\ &= \rho \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m e^{(ikx_n \cdot x - k_{nm} \cdot z)} \\ &\quad [ A_{nm}(t) e^{iky_m \cdot y} + A_{nm}^*(t) e^{-iky_m \cdot y} ] \end{aligned} \quad (81)$$

the acceleration at any point  $(x, y, z)$  coincident with a unit normal vector  $(n_x, n_y, n_z)$  may be written as

$$\vec{a}_{FS} \cdot \vec{n} = -g \sum_{n=1}^{N_{kx}} \Delta kx_n \sum_{m=1}^{N_{ky}} \Delta ky_m e^{(ikx_n \cdot x - k_{nm} \cdot z)}$$

$$[ A_{nm}(t) \cdot e^{iky_m \cdot y} (iky_n \cdot n_x + iky_n \cdot n_y - k_{nm} \cdot n_z) \\ + A_{nm}^*(t) \cdot e^{-iky_m \cdot y} \cdot (ikx_n \cdot n_x - iky_m \cdot n_y - k_{nm} \cdot n_z) ] \quad (82)$$

### 2.5.6 Ambient Wave Field Representation

The ambient wave field is represented by a linear wave system of amplitude  $A$ . Consider unidirectional, regular waves and define the velocity potential as

$$\phi_A(x, z, t) = -\frac{Ag}{\omega} e^{-kz} \sin(kx - \omega t) \quad (83)$$

The  $x$  and  $z$  components of velocity can then be expressed as

$$v_x(t) = -\frac{\partial \phi_A}{\partial x} = \frac{Agk}{\omega} e^{-kz} \cos(kx - \omega t) \quad (84)$$

$$v_z(t) = -\frac{\partial \phi_A}{\partial z} = -\frac{Agk}{\omega} e^{-kz} \sin(kx - \omega t) \quad (85)$$

The  $x$  and  $z$  components of acceleration can be given as

$$a_x(t) = \frac{\partial v_x}{\partial t} = Agk e^{-kz} \sin(ky - \omega t) \quad (86)$$

$$a_z(t) = \frac{\partial v_z}{\partial t} = Agk e^{-kz} \cos(kx - \omega t) \quad (87)$$

The dynamic pressure may be expressed as

$$p_A(t) = -\rho \frac{\partial \phi_A}{\partial t} = -Ae^{-kz} \cos(kx - \omega t) \quad (88)$$

We can now evaluate the normal acceleration and pressure induced at the center of each panel by the ambient wave field. These quantities are used in Steps 1 and 4 of the simulation procedure. The pressure is given in (88) and the normal acceleration is simply

$$\vec{a}_A \cdot \vec{n} = \vec{a}_x \cdot \vec{n}_x + \vec{a}_z \cdot \vec{n}_z \quad (89)$$

where the velocity components are given in (84) and (85). We will assume that in an irregular wave system, the total velocity, acceleration and pressure components can be described as the superposition of individual single frequency components.

## 2.6 HULL GIRDERS LOADS

Hull girder loads are computed in the conventional manner of strip theory where the dynamic shear force at a cross section is the difference between the inertia force and the sum of external forces acting on the portion of the hull forward of the section. The vertical shear force and bending moment at any location  $x_0$  along the ship's length is, in the original coordinate system,

$$SF_y(x_0) = \int_{x_0} \frac{df}{dx} y \, dx \quad (90)$$

and

$$BM_y(x_0) = \int_{x_0} (x-x_0) \frac{df}{dx} y \, dx \quad (91)$$

where

$$\frac{df}{dx} y = -\delta m (\ddot{y} - x \ddot{\psi}) + \frac{dy_h}{dx} + \frac{dy_w}{dx} + \frac{dy_f}{dx} + \frac{dy_b}{dx} + y_q \quad (92)$$

and  $\delta m$  = local sectional mass. Integrations are performed from the location  $x_0$  forward to the bow.

The lateral shear force, bending moment and torsional moment are given as

$$SF_z(x_0) = \int_{x_0}^{bow} \frac{df_z}{dx} dx \quad (93)$$

$$BM_z(x_0) = \int_{x_0}^{bow} (x - x_0) \frac{df_z}{dx} dx \quad (94)$$

$$TM_x(x_0) = \int_{x_0}^{bow} \frac{dm_x}{dx} dx \quad (95)$$

where

$$\begin{aligned} \frac{df_z}{dx} &= -\delta m(\ddot{z} - \ddot{x}\phi - \bar{y}\ddot{\theta}) \\ &\quad + \frac{dZ_h}{dx} + \frac{dZ_w}{dx} + \frac{dZ_b}{dx} + z_q \end{aligned} \quad (96)$$

$$\begin{aligned} \frac{dm_x}{dx} &= -i_x \ddot{\theta} - \delta my (\ddot{z} - \ddot{x}\phi) \\ &\quad + \frac{dK_h}{dx} + \frac{dK_w}{dx} + \frac{dK_b}{dx} + K_q \end{aligned} \quad (97)$$

and  $\bar{y}$  = local section's center of gravity relative to ship c.g. (positive up).

$i_x$  = local section's mass moment of inertia.

## 2.7 NUMERICAL ASPECTS

### 2.7.1 Solution Procedures - Two-Dimensional Approach

The equations of motion as represented by expressions (4) - (7) are numerically integrated for each time to yield velocities and displacements. The fourth-order Runge-Kutta scheme is used for this purpose. At each time step, two-dimensional hydrodynamic coefficients are evaluated for each section for either the still water draft or at the instantaneous depth of immersion, at the option of the user. When it is desired that the hydrodynamic coefficients be draft dependent, the coefficients are obtained by linear interpolation from an array of six values corresponding to six drafts which cover a

range specified by the user in the input data. Since the hydrodynamic coefficients are also frequency dependent, they are selected using linear interpolation from an array of twelve values associated with a range of twelve frequencies specified by the user. Thus, when the two-dimensional sectional coefficients are to be both draft and frequency dependent, two-dimensional linear interpolation is performed.

There are two methods for the selection of frequencies at which to evaluate the hydrodynamic coefficients. One is based on a scheme that samples the previous two zero-crossing periods of sectional motion in sway, heave and roll. The two values are averaged, and three characteristic frequencies are derived for evaluation of the sectional hydrodynamic coefficients. The sway-roll or roll-sway coefficients are (arbitrarily) linked to the sway characteristic frequency. The other allows the user to specify a frequency, such as the peaks of the response spectra or peak of the wave energy spectrum.

The sectional hydrodynamic coefficients are computed using the Frank close-fit method. Spatial derivatives of added mass and damping coefficients in the  $x$ -direction are approximated by center-space finite differences. In the calculation of the derivative of added mass with respect to the relative wave elevation used in the computation of vertical flare force, the added mass is evaluated at each time step at the instantaneous immersed draft of the section. For each time step interval  $\Delta t$ , the change in added mass is computed and divided by the change in instantaneous draft of the section. During water exit, the calculation of the impact term is not performed and the sectional flare force is set to zero.

### 2.7.2 Solution Procedures - Three-Dimensional Analysis

#### Specification of Parameters for Free Surface Harmonics

There are three parameters which must be chosen. These parameters dictate the wave numbers and wave number spacing for the free surface representation. The following parameters are to be specified for the three-dimensional transient analysis:

$L_x, L_y$  - maximum distances in  $\pm x$  and  $\pm y$  from body origin defining the physical region over which the wave field is required.

$T$  - maximum time interval for transient simulation.

$l_x, l_y$  - minimum half-wavelength related to the smallest scale of disturbance or physical feature of the hull that needs to be represented.

There are no set rules for the selection of these parameters, and their choice must be based on an understanding of the problem. There are, however, some

guidelines which generally seem to work well. The values of  $L_x$  and  $L_y$  should be 2 to 2.5 times the length and beam of the body, respectively. The values of  $l_x$ ,  $l_y$  should be on the order of the average dimensions of the hull panels. The parameter  $T$  can be set to about 60% of the actual time for which a transient analysis is desired.

The wave numbers and wave number spacing are then specified according to the following relations:

(a) Maximum step sizes for  $kx_n$  and  $ky_m$  are:

$$\begin{aligned} kx_{n+1} - kx_n &< \frac{2\pi}{L_x} \\ ky_{m+1} - ky_m &< \frac{2\pi}{L_y} \end{aligned} \quad (98)$$

(b) The minimum upper bounds of  $kx$  and  $ky$  are:

$$\begin{aligned} kx_{N_{kx}} &\geq \frac{2\pi}{l_x} \\ ky_{N_{ky}} &\geq \frac{2\pi}{l_y} \end{aligned} \quad (99)$$

(c) Another set of conditions for wave number spacing is:

$$\begin{aligned} \sqrt{kx_{n+1}} - \sqrt{kx_n} &< \frac{2\pi}{(T\sqrt{g})} \\ \sqrt{ky_{m+1}} - \sqrt{ky_m} &< \frac{2\pi}{(T\sqrt{g})} \end{aligned} \quad (100)$$

A physical interpretation of the wave number spacing required by the above conditions has been pointed out by Chapman [5]. The wave numbers defined by (98), (99), and (100) correspond in the physical domain to "vertical walls"

which must be placed sufficiently far away from the body so that the free surface disturbances generated near the body do not reflect back over the time interval. Associated with the faster propagating, longer wavelengths are vertical walls placed further away - the shorter wavelength walls are nearer. The result is that the time interval for each wave to reflect is equal. For further discussion of the reasoning behind this method of wave number spacing and selection criteria, see [5].

#### Integration with Equations of Motion

At a time specified by the user, the three-dimensional transient analysis can start, using accelerations and velocities generated by the solution of the equations of motion at that time step. Then, data generated (pressures and loads) from the three-dimensional analysis is not used for a period of time specified by the user, so-called "start-up" time. This allows the free surface disturbance to fully develop since, initially, there exist no radiated or diffracted waves within the three-dimensional simulation. Based on the present level of experience with the program, the minimum start-up time for ship forms has not been fully defined; however, for a sphere, two full cycles of motion appear sufficient.

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### 3.0 NUMERICAL RESULTS

Several computer codes have been developed according to the predictive techniques discussed in the previous sections. The main program is entitled SSX (Ship Simulator, Experimental). It performs the simulation of ship motions, hull girder loads and hull pressures. There are two preprocessing programs - HYDREX2 and HYDREX3. The program HYDREX2 computes sectional added mass and damping coefficients for an array of twelve frequencies and six drafts using the Frank close-fit technique. The program also calculates general hydrostatic data for each of the six drafts. The program HYDREX3 computes areas, normals and panel center coordinates for the panel (either quadrilateral or triangular) representation of the hull. It also evaluates three computationally demanding arrays used for the simulation of hull pressures. For further information about these programs, refer to Volume II (Program Manual).

Because the debugging and testing of SSX or any time simulation program, for that matter, is an extremely time-consuming process, the extent of the validation effort has been limited to the minimum number of cases needed to test the capabilities of the computer programs and verify the basic theory and numerical techniques when possible.

#### 3.1 TWO-DIMENSIONAL HYDRODYNAMIC COEFFICIENTS

Sectional added mass and damping coefficients computed by Program HYDREX2 for the SL-7 containership were checked against values generated by a conformal mapping method, as given by Zielinski [33]. Agreement was excellent in most cases. As an example, Figure 4 compares added mass and damping coefficients for heave and sway at midships with a draft of 32.8 feet.

#### 3.2 MOTION RESPONSE AND HULL GIRDER LOADS IN SMALL AMPLITUDE REGULAR WAVES

A few comparisons between computed and experimental values for heave and pitch motions in one-foot regular waves will first be presented to check the time-domain solution methods using strip theory computed forces where the added mass and damping coefficients are calculated for the mean still water sectional drafts. Figure 5 shows the heave and pitch amplitudes and phases for the Series 60 standard hull form with block coefficient 0.70 at Froude numbers 0.15 and 0.20. The points in the figures represent experimental results by Gerritsma and Beukelman [34]; the solid line is computed by the present method, and the broken line by modified strip theory (frequency domain) of Gerritsma and Beukelman. Note that the pitch amplitude is scaled by wave slope. It is seen that agreement is generally good with the exception of heave amplitude in the vicinity of  $\lambda/L = 1.0$ . The reason for this disagreement has not been identified.

Figure 6 gives the theoretical and experimental pitch and heave values for the SL-7 containership at 25 knots in a full load condition. The experimental values shown are by Dalzell [35]; the solid line represents the present

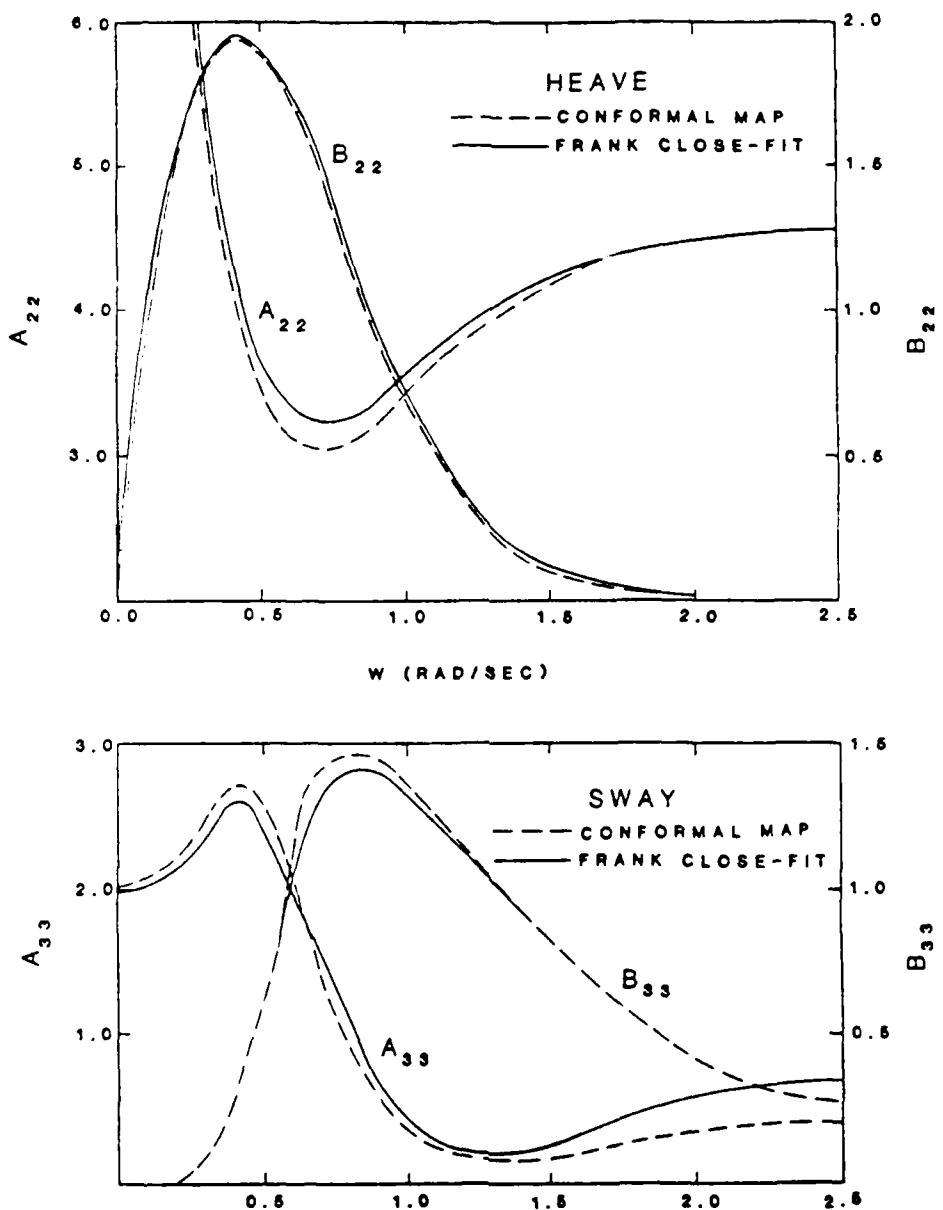


Figure 4 Added mass and damping coefficients. Comparison of HYDREX2 (Frank close-fit) with CGSCORES (Conformal Mapping). SL-7 Containerships, Midships section.

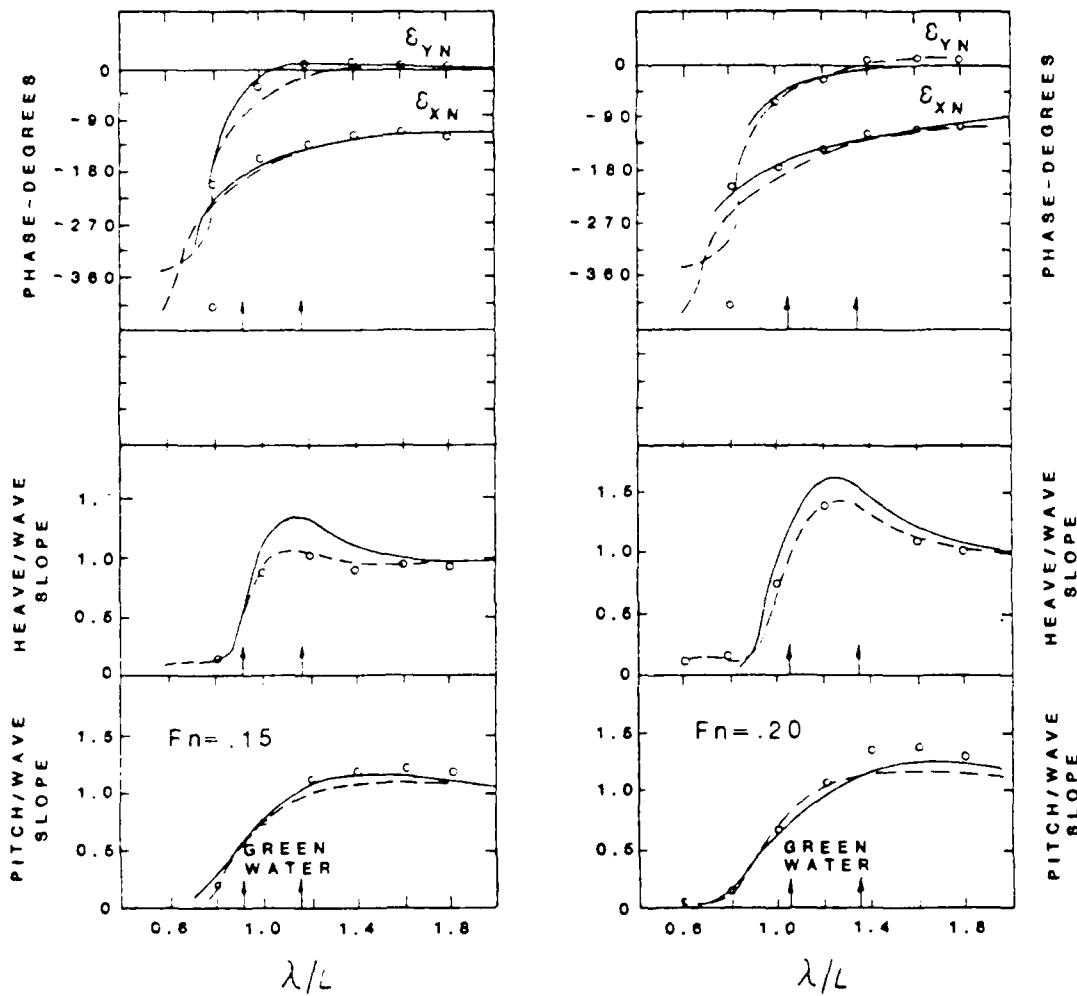


Figure 5 Calculated and measured amplitude and phase characteristics for heave and pitch. Series 60. Block coefficient 0.70. Froude Numbers 0.15 and 0.20.

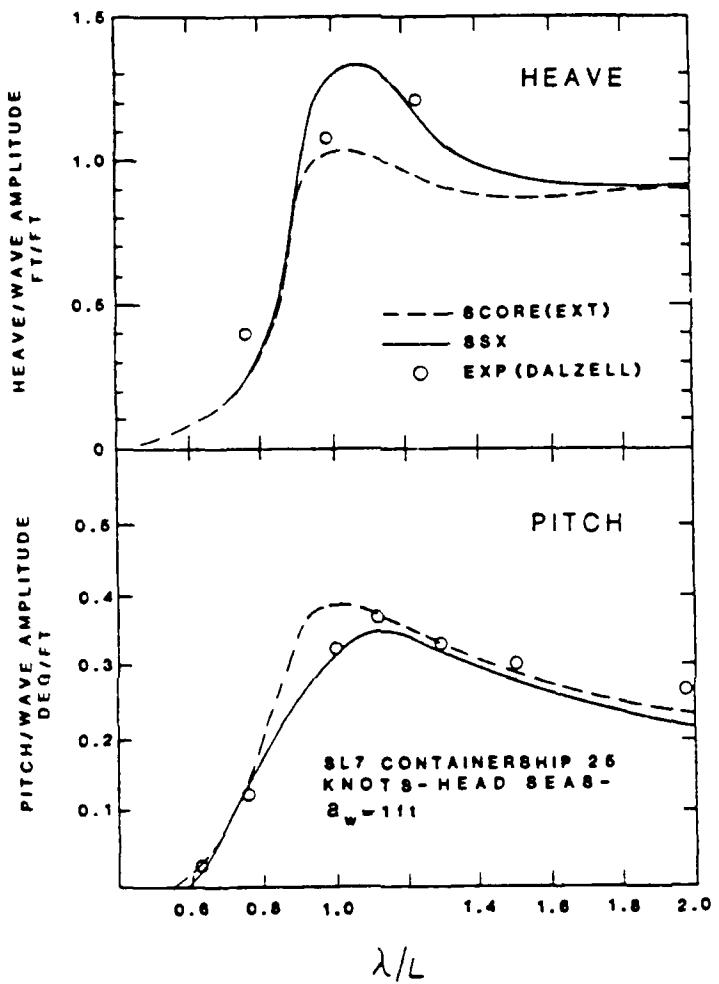


Figure 6 Calculated and measured amplitudes of heave and pitch. SL-7 Containership. 25 knots, head seas.

method, and the broken lines are strip theory results from the SCORES Program [4]. Note that the experimental values for heave at longer wave lengths have not been included because it has been suggested [35] that they were too large and are in error. (The short wavelength experimental values are assumed to be correct.) It is seen that pitch values predicted by SSX agree well with the other values. Heave response, like before, is too high around  $\lambda/L = 1.0$ .

The routine to compute hull girder loads in the present version of SSX is still in a premature stage. The computation of moment arms and sectional inertial forces essentially assumes a lumped mass model. There is no attempt to account for "trapezoidal" sections of the weight curve. Also, weight segments must correspond to the segment between adjacent stations. However, the routine, as written, does provide the means to evaluate the effect of including various forces or different techniques by which to evaluate such forces.

A comparison between computed and experimental midships bending moment amplitudes for the SL-7 containership at 25 knots in a full load condition is shown in Figure 7. The experimental data is from Dalzell [35]; the present theory is represented by the solid line, the broken line shows predictions from SCORES [4]. Agreement is shown to be very good.

Finally, comparison between theory and experiments for midships horizontal and vertical bending moments and pitch angle are shown in Figure 8 for the SL-7 in oblique waves ( $210^\circ$ ). Agreement is satisfactory with the exception of vertical bending moment. Further investigation is needed to identify the causes of disagreement.

### 3.3 IRREGULAR WAVES

A test case was run to check the program's ability to predict motion and loads response in an irregular sea. The SL-7 was subjected to an irregular head sea wave system approximately representing a Bretschneider spectral formulation with  $H_s = 10.8$  ft and  $T_o = 8$  secs, where  $H_s$  is significant height

and  $T_o$  is the period associated with the peak of the sea spectrum. Forward speed was 5 knots. The frequency at which hydrodynamic coefficients used for ship motion-induced forces were to be calculated was set to .8217 - the encounter frequency associated with the peak of the sea spectrum. The sea spectrum was decomposed into ten components. Randomly generated phase angles were used to generate the irregular sea, superimposing the ten regular wave components. A real time simulation of 20 minutes was carried out. Statistics were acquired for heave, pitch and midship's vertical bending moment. Table 1 compares the statistical results of the simulation with predictions from the strip theory frequency domain program developed at MIT and described by Loukakis [36].

As can be seen, the SSX motion values are slightly higher than the MIT program values. The vertical bending moments compare very well. The measured significant RMS wave height from the SSX simulation was close to the desired value of 5.33, providing some assurance that the irregular wave spectrum is correctly being broken down into wave components.

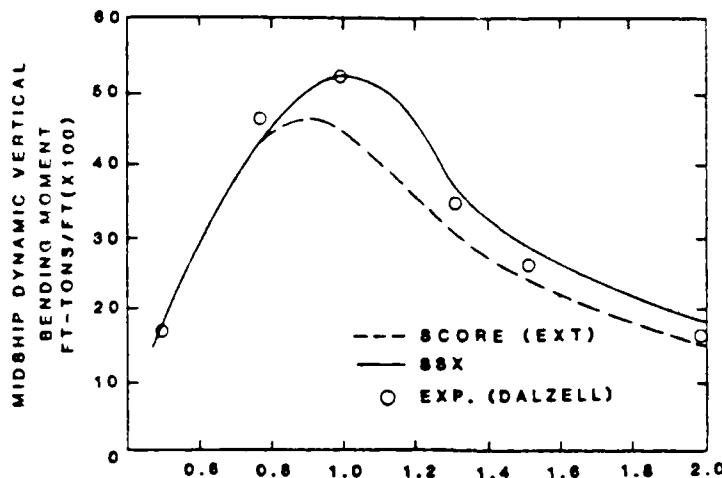


Figure 7 Midship Dynamic Vertical Bending Moment for SL-7 Containership.  
25 knots, head seas, full load, regular waves, ampl. = 1 ft.

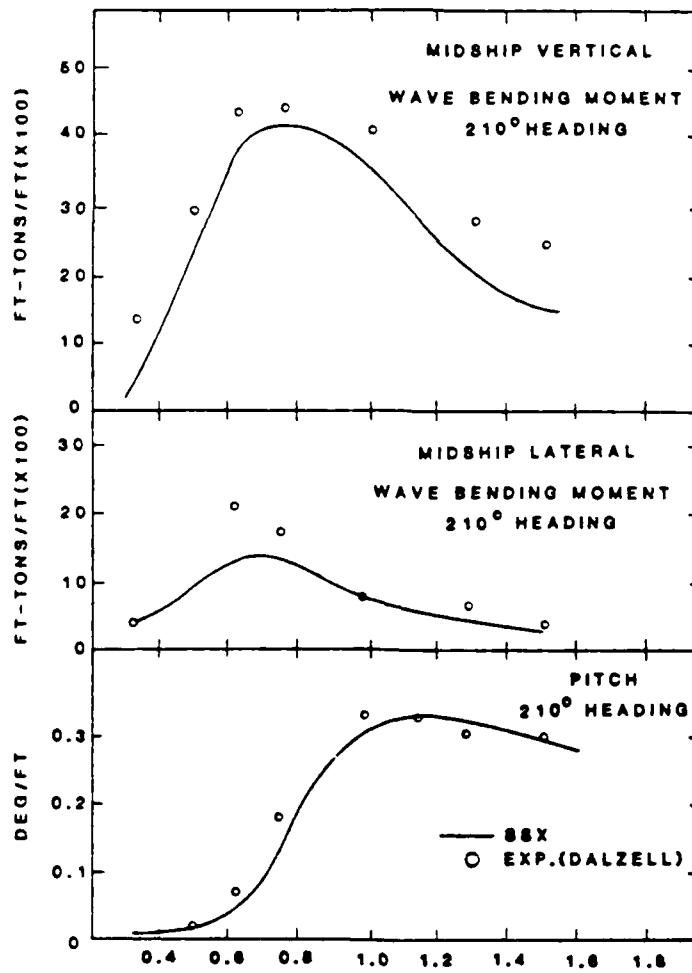


Figure 8 Midship Vertical, Horizontal Wave Bending and Pitch. SL-7  
Containership, 25 knots, 210° heading.

Table 1

	SSX	MITA
RMS Pitch (deg)	.2644	.2606
RMS Heave (ft)	.5560	.5308
RMS V.B.M. (ft-tons)	56844	56415
RMS Wave Height	5.23	5.33

One feature of the SSX program is the scheme to average the two most recent zero-crossing periods and derive a "characteristic" frequency at which sectional hydrodynamic coefficients are calculated. This feature was applied to the same test case as before. The results are shown in Table 2.

Table 2

	SSX	
	with f (freq)	without f (freq)
RMS Pitch (deg)	.2619	.2644
RMS Heave (ft)	5507	.5560
RMS V.B.M. (ft.-tons)	55432	56844

The effect of invoking the characteristic frequency feature is to reduce the SSX values. The calculated sectional characteristic heave frequency during the course of the simulation generally ranged between  $\omega = .35$  and  $.49$ . This reflects the actual response of the ship and is significantly different from the  $.8217$  value used in the previous simulation. There is still relatively little difference between the RMS values of the two test cases.

### 3.4 NONLINEAR RESPONSE IN LARGER WAVES

As part of many model-test programs, a so-called linearity check is performed where the same test runs are made with increasing wave amplitudes to determine if responses are linearly proportional to wave amplitude. Similar experiments have been performed using SSX. The runs were made at 25 knots in head seas with wave amplitudes of 5, 10 and 15 feet. Added mass and damping coefficients were computed at the mean still water draft. Plots showing peak heave, pitch and midship's vertical bending moment are provided in Figures 9, 10 and 11, respectively.

Note that in Figures 9 and 10, the heave and pitch response has been divided by wave amplitude. In both of these figures, nonlinear behavior is exhibited; that is, normalized response is reduced at higher amplitudes, with the exception of the pitch "bow-down" response. It appears quite linear. In Figure 11, the midship's vertical wave bending moment is shown for various wave lengths and wave heights. Note that in this plot, the response has not been normalized by wave amplitude. In general, response is linear with respect to wave amplitude, with the exception of slight nonlinearities shown for hogging at 15 feet wave amplitude for  $\lambda/L = 0.75, 1.0, 1.25$ .

Also shown in Figure 11 is the effect of including the flare impact force. The broken lines show the bending moment when flare is included. The effect is only measurable in sagging. The values for hogging were so close to the non-flare values that, if drawn, they would be coincident with the lines shown already. (For hogging, a slight reduction in the magnitude of bending moment was the effect of including flare forces.)

The effect of including flare forces on the heave and pitch response is rather minor except around  $\lambda/L = 1$ , as shown in Figures 12 and 13, respectively. The heave and pitch response is shown for a ten-foot regular wave over a range of wave lengths. As shown in Figures 12 and 13, the effect of flare force inclusion is to reduce the amplitudes in both directions (heave up and down, pitch bow-up and bow-down) between  $\lambda/L = 1.0$  and  $1.25$ . It can also be seen in these figures that for this wave amplitude, the SL-7 containership pitches bow-down more than bow-up, and heave-down more than heave-up over the range of wavelengths.

Linearity checks were performed up to regular wave amplitudes of 15 feet because, at 20 feet and above, inconsistent results were sometimes obtained from the program. A check of what was physically occurring at these greater wave amplitudes was performed graphically. Figures 14 and 15 show the motion of the SL-7 containership at 25 knots for  $\lambda/L = 1.5$  and  $1.75$ , respectively. It can be seen that for  $\lambda/L = 1.5$ , bow submergence and emergence are quite extreme. For  $\lambda/L = 1.0$  and  $\lambda/L = 1.25$ , behavior was equally extreme.

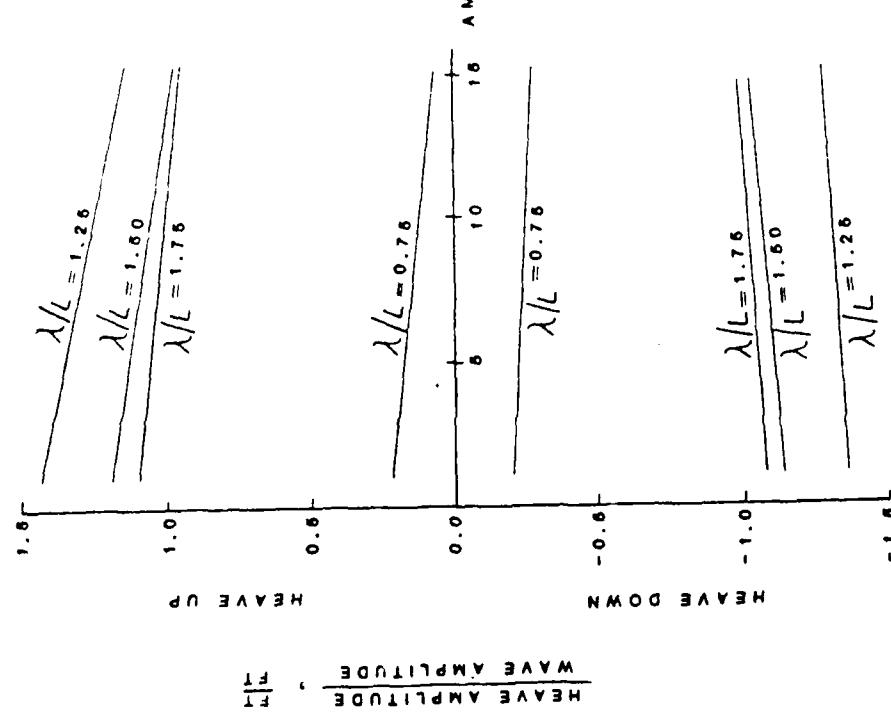


Figure 9 Heave Amplitude/Wave Amplitude vs. Wave Amplitude. SL-7 Container ship, 25 knots, full load condition, Head Seas.

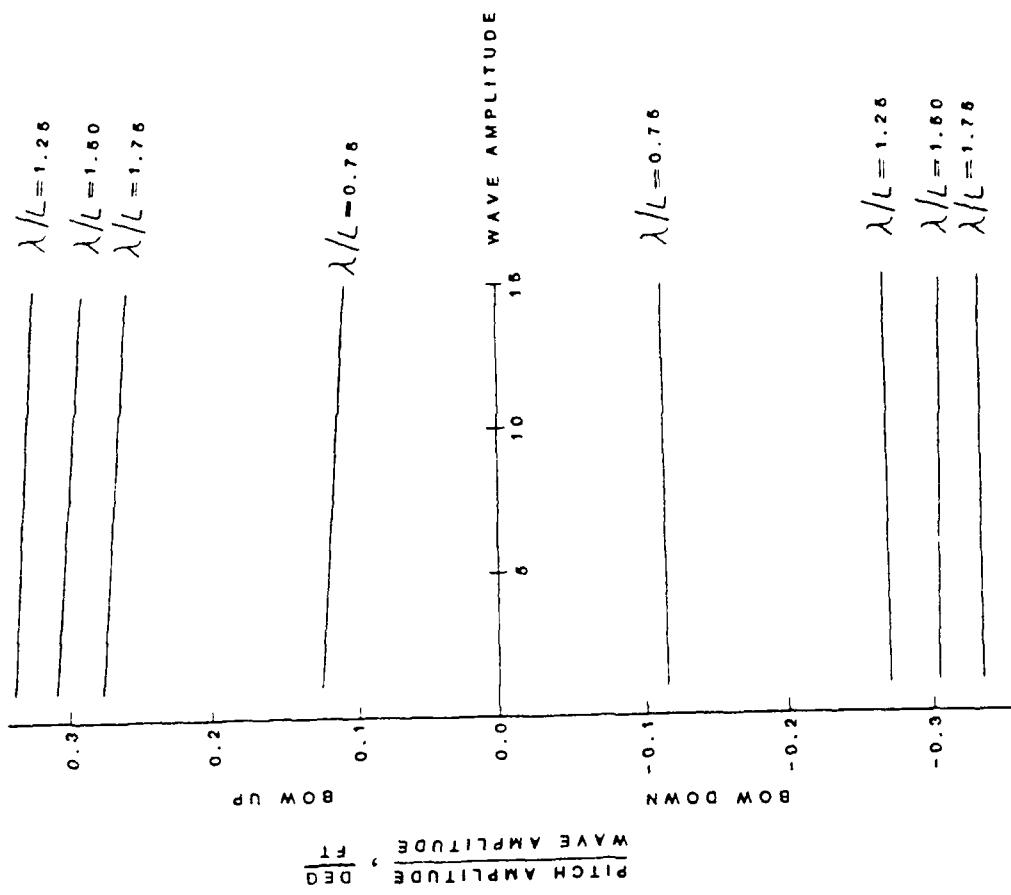


Figure 10 Pitch Amplitude/Wave Amplitude vs. Wave Amplitude. SL-7 Container ship, Full Load, Head Seas, 25 knots.

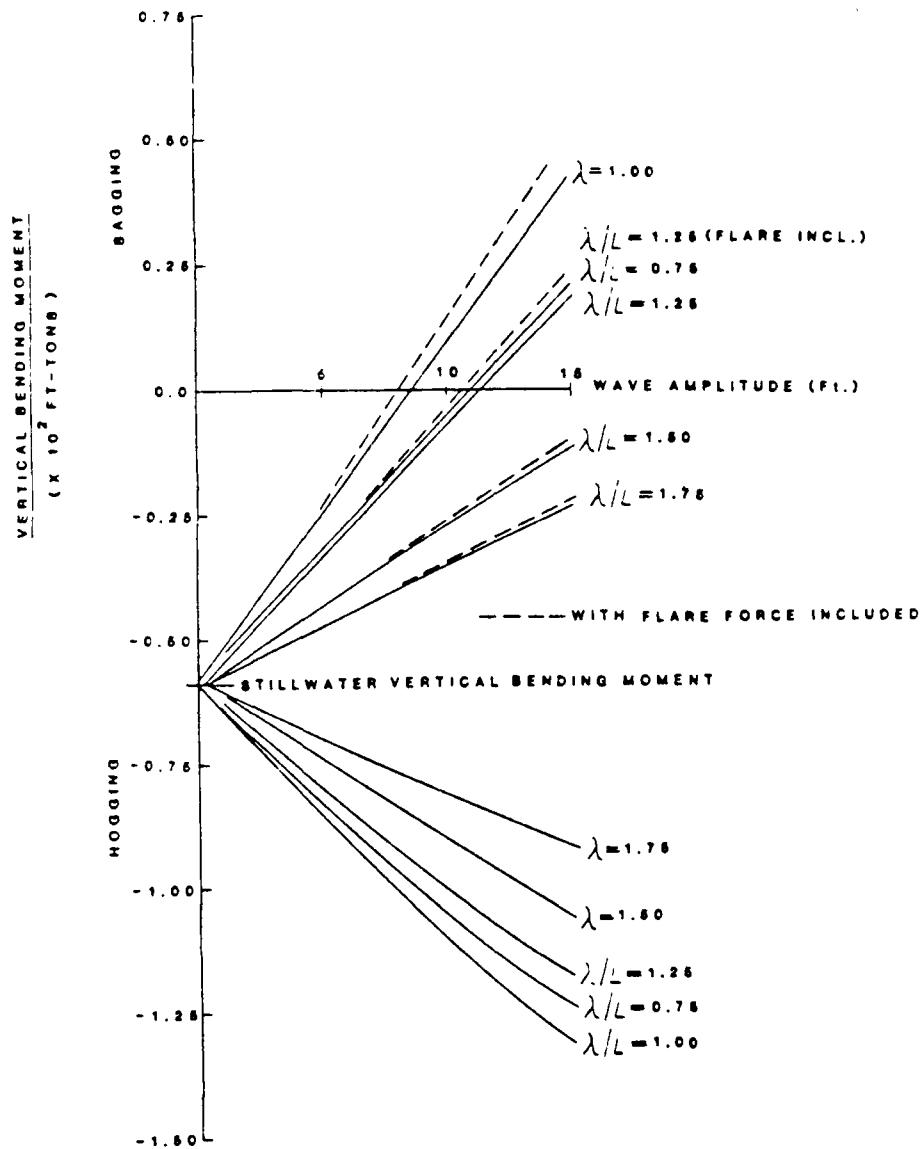


Figure 11 Midship Vertical Bending Moment, SL-7 Containership, 25 knots, head seas (effect of flare on sagging shown).

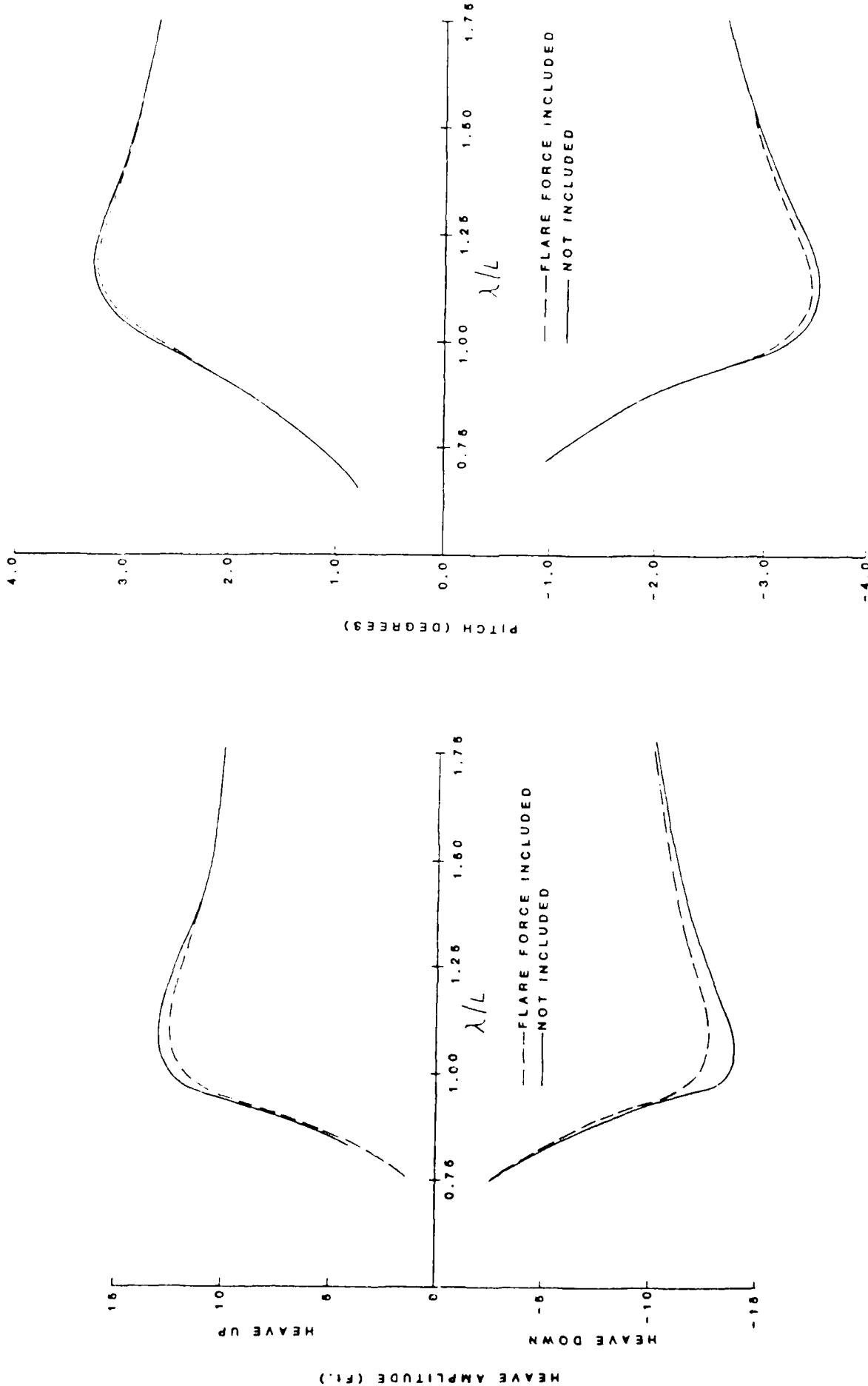


Figure 12 Heave Amplitude vs. Wavelength/Shiplength.  
Comparison of Theoretical Prediction with  
and without flare force included

Figure 13

Pitch Amplitude vs. Wavelength/Shiplength.  
Comparison of Theoretical Prediction with  
and without flare force included.

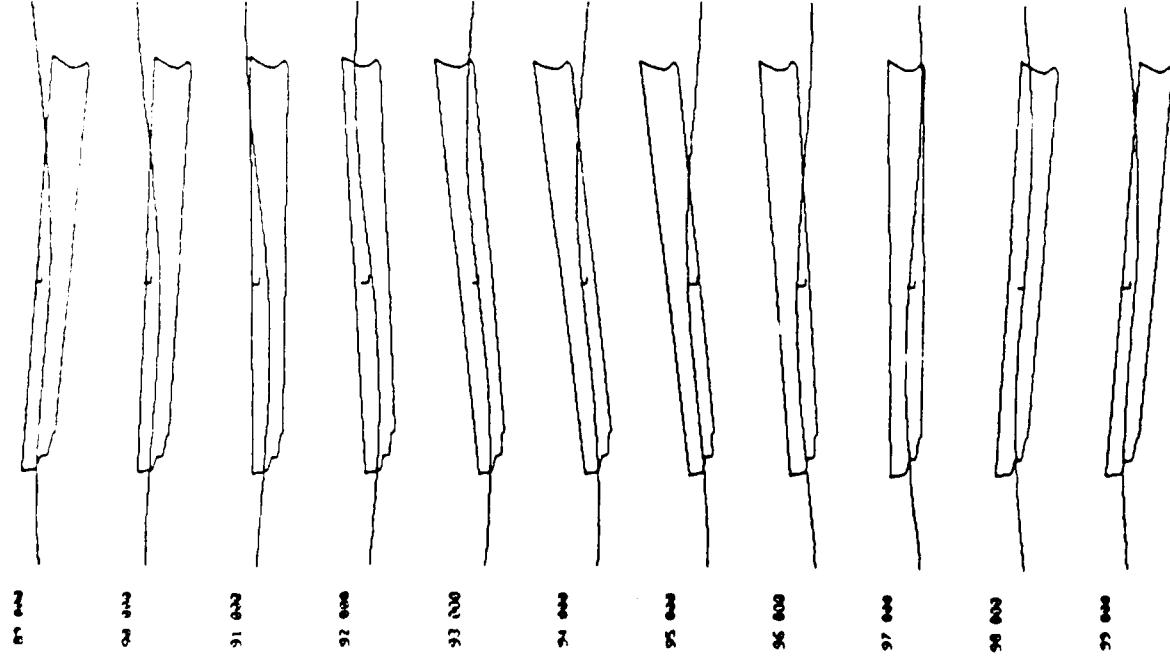


Figure 14 SL-7 Containership in Head Seas at 25 knots. Wavelength/  
Shiplength = 1.5.

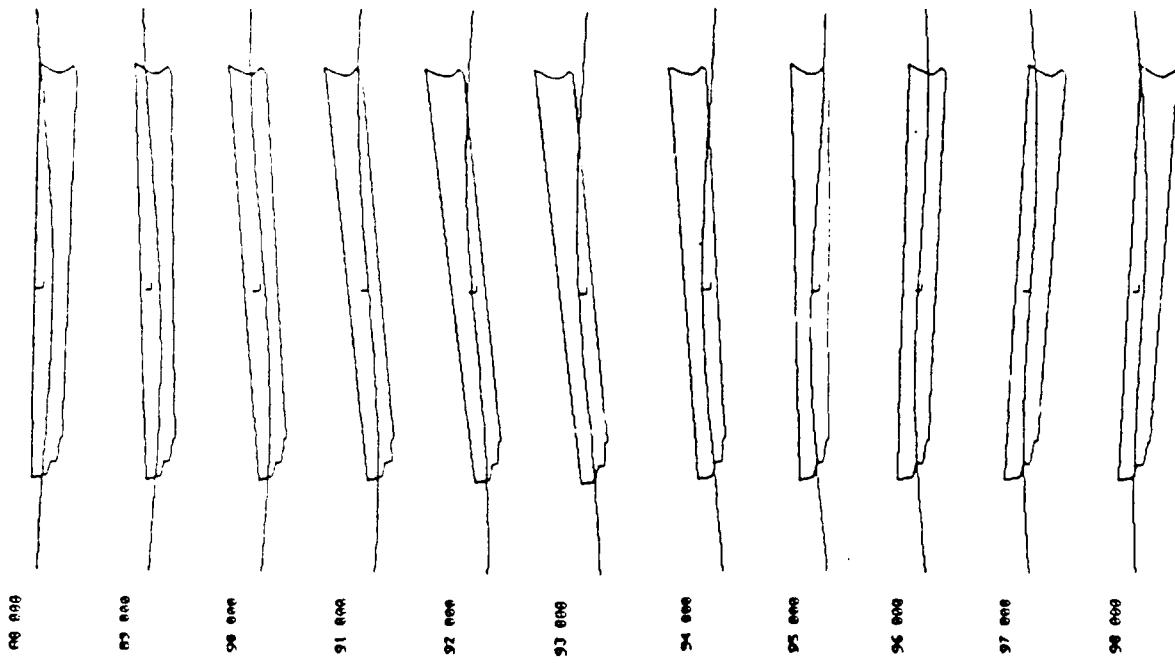


Figure 15 SL-7 Containership in Head Seas at 25 knots. Wave Amplitude = 20 ft, Wavelength/Shiplength = 1.75.

### 3.5 INFLUENCE OF DRAFT-DEPENDENT HYDRODYNAMIC COEFFICIENTS

In order to evaluate the influence of calculating the sectional added mass and damping coefficients at the actual draft (average) at each station for each instant, a series of runs were made at 25 knots in head seas,  $\lambda/L = 2.0$ . Flare forces were not included in these runs. Wave amplitudes were 5, 10 and 20 feet. It was found that within this range of conditions, the use of draft-dependent coefficients had negligible effect on pitch and heave motions and vertical wave bending moment.

### 3.6 FORCE PREDICTION USING THE THREE-DIMENSIONAL APPROACH

The ability of Chapman's method for the prediction of transient motions of a floating body is demonstrated in [5] with the forced oscillation and free oscillation of a two-dimensional rectangle and wedge. Chapman extends the two-dimensional model to three dimensions as reported in [6]. The technique used by Chapman to check the three-dimensional model was to subject a semi-submerged sphere represented by 60 panels to vertical impulse - a unit step in heave velocity. The heave response time history that results is used to derive added mass and damping coefficients. These coefficients are compared with classical results of Havelock [37] and results of Kim [38] with very good correlation.

The basic ability of the three-dimensional method developed here to accurately predict hydrodynamic forces will be verified by two simple tests using a semisubmerged sphere at zero speed. A more comprehensive set of tests is recommended in the future. The two tests presented here should, however, clearly demonstrate that this method has considerable possibilities.

In the first test, the sphere will be subjected to forced vertical oscillations of unit amplitude at various frequencies in otherwise calm water. From the measured pressures, the total vertical time-varying force on the sphere will be calculated, which is then used to derive added mass and damping coefficients. The added mass and damping coefficients can then be compared to the results of Havelock [37].

In the second test, the sphere will be restrained and subjected to regular unidirectional waves of various frequencies and unit amplitude. Wave exciting forces in heave and surge can be measured and compared with analytical predictions given by Garrison [39].

The numerical particulars for both tests are given in Table 3.

#### Forced Vertical Motions of Sphere

In the first simulation, the semisubmerged sphere is subjected to vertical oscillations of unit amplitude at wave numbers

$$k^2 = \frac{\omega}{g} = 0.4, 0.8, 1.0, 1.2, 1.6 \text{ and } 2.0.$$

The total vertical force was measured over two to three full cycles, depending on the frequency, up to about 20 seconds of simulation time with time steps of 0.2 seconds. The last cycle of the simulation was evaluated to derive added mass and damping coefficients using the method described below.

Table 3  
Numerical Parameters

NPAN = number of panels	= 72
$L_x$ = maximum length scale in X	= 0.25
$l_x$ = minimum length scale in X	= 2.5
$L_y$ = maximum length scale in y	= 0.25
$l_y$ = minimum length scale in y	= 2.5
T = maximum time scale	= 12 sec.
g = gravitational acceleration	= 1.0
$\rho$ = fluid density	= 1.0
a = sphere radius	= 1.0
$\Delta t$ = time step size	= 0.1

The vertical displacement of the sphere from its mean position is given by

$$y = A \sin \omega t.$$

The linearized equation of motion for the sphere in forced heave is

$$(m + a) \ddot{y} + b \dot{y} + c y = Y_T.$$

where

m	= mass of the cylinder,
a	= hydrodynamic or "added" mass in heave,
b	= damping coefficient against vertical motion,
c	= hydrostatic restoring coefficient against vertical displacement, and
$Y_T$	= external driving force.

The total hydrodynamic force acting on the body in the vertical direction is

$$Y_h(t) = a \ddot{y} - b \dot{y}.$$

Assuming this hydrodynamic force is a harmonic function in time and can be written as

$$Y_h(t) = \gamma \sin(\omega t - \epsilon),$$

the hydrodynamic coefficients are obtained by equating these two expressions for  $Y_h$ ,

$$a = \frac{\gamma \cos \epsilon}{\omega^2 A}$$

and

$$b = \frac{\gamma \sin \epsilon}{\omega A}.$$

The amplitude  $\gamma$  and phase shift  $\epsilon$  are obtained by comparing plots of the displacement and dynamic pressure force  $Y_h$  acting on the sphere as functions of time and measuring the shift in phase. A comparison of the results obtained with Havelock's results is shown in Figure 16. The solid line is Havelock's results. The numerical predictions are shown as circles. As can be seen from Figure 16, agreement is excellent.

Figure 17 shows a time sequence of the free surface disturbance induced by the vertical motion of the sphere. The circle represents the mean still waterline of the sphere. The radius of the sphere is 1.0 and the dimensions of the free surface area shown are  $8 \times 8$ . The wave number for the sequence is  $k = 1.0$ . The internal standing waves inside of the sphere are shown. (These internal standing waves should produce no net pressure.)

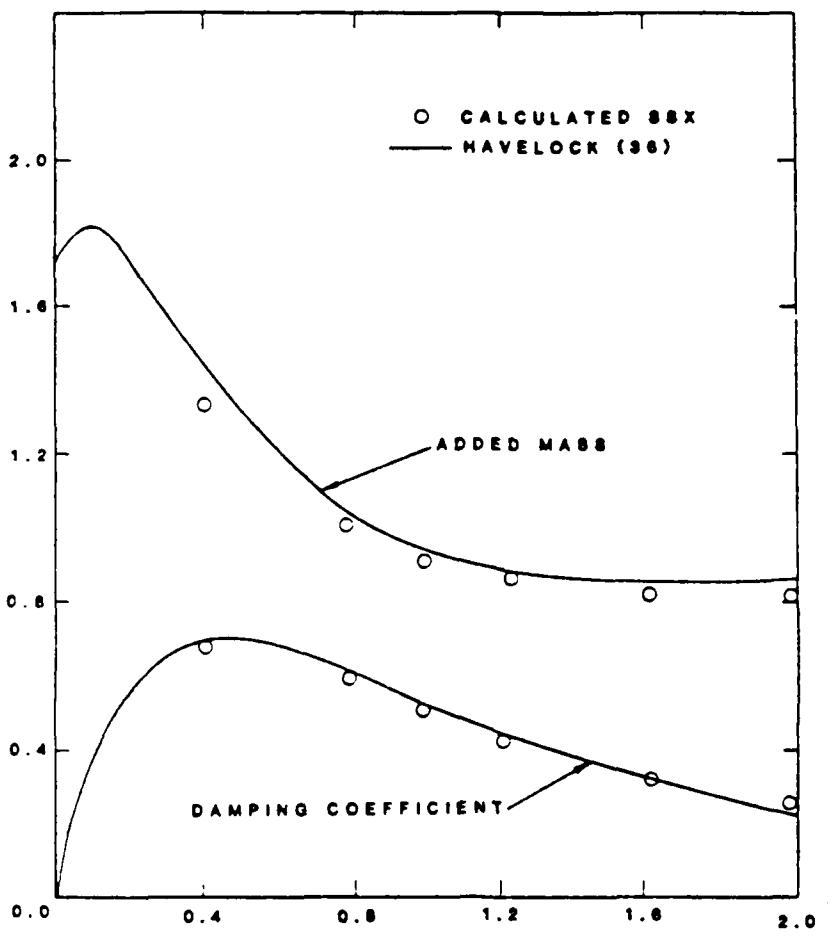
#### Wave Excitation Forces on Semisubmerged Sphere

The purpose of the second simulation was to investigate forces on the sphere when subjected to regular waves of different frequencies. Figure 18 shows the comparison between analytical predictions from Garrison [38] for the heave and surge wave exciting forces on a semisubmerged sphere. The agreement is excellent.

Figure 19 shows the diffraction wave system that develops from regular waves ( $h = 1.4$ ) imposed on the sphere. The ambient wave amplitudes have been subtracted out of the free surface plot to more clearly exhibit the diffracted waves.

#### Other Tests

Attempts were also made to: (a) test a semisubmerged sphere in forced vertical oscillations at a uniform forward speed; and (b) to conduct forced oscillation tests for ellipsoids with L/B ratios of 8:1 and 4:1. In each of these cases, forces quickly increase to unrealistic levels, clearly indicating



$$\frac{w^2 \bar{a}}{g} \quad \left\{ \begin{array}{l} \bar{a} = \text{RADIUS} \\ g = \text{GRAVITATIONAL ACCELERATION} \\ w^2 = \text{FREQUENCY} \end{array} \right.$$

Figure 16     Added Mass and Damping Coefficients  
for semisubmerged sphere.

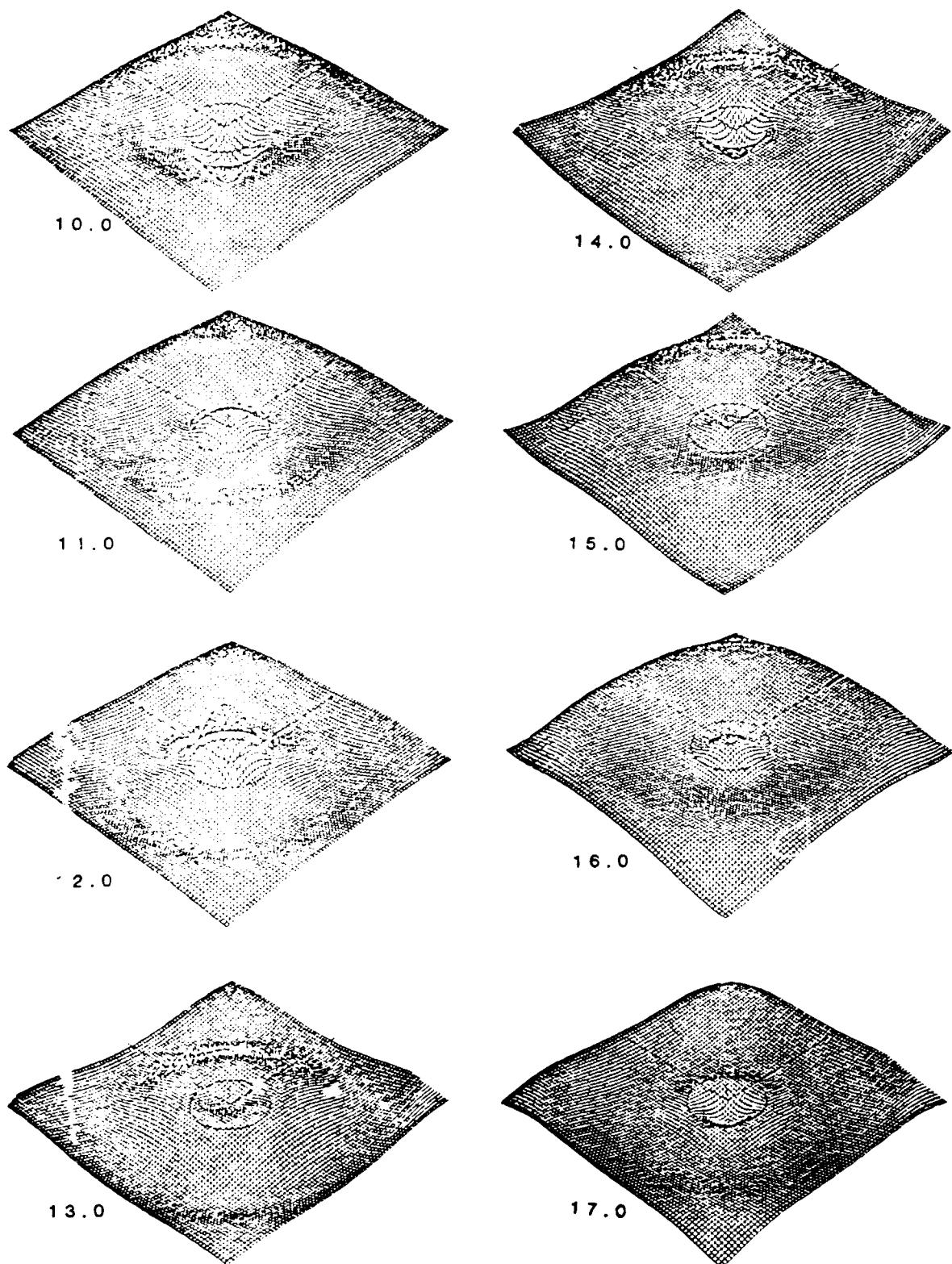


Figure 17 Radiated waves from vertically oscillating sphere at  $k = 1.0$ .  
Time = 10 - 17 secs after startup.

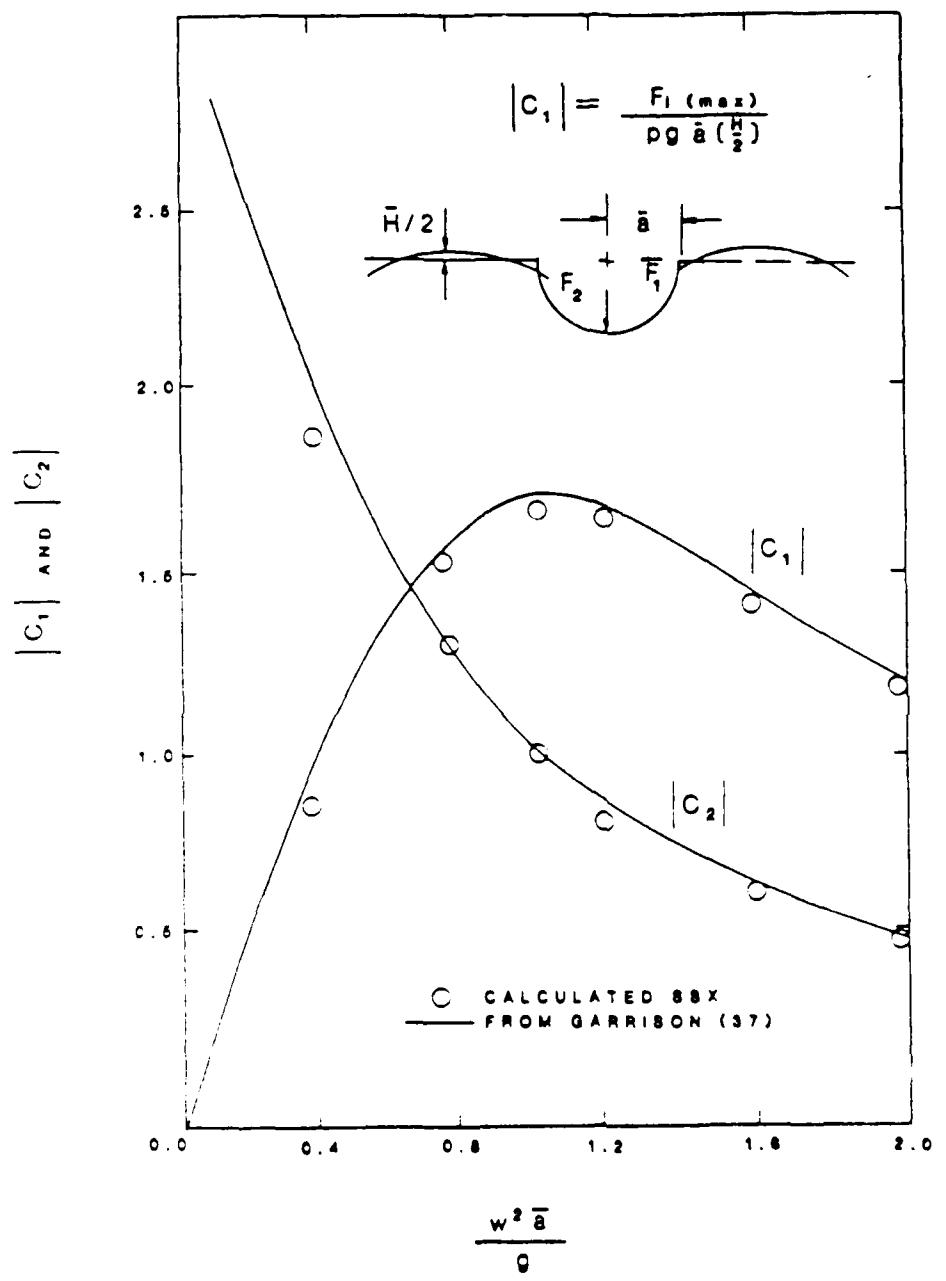


Figure 18 wave excitation forces for semisubmerged sphere.

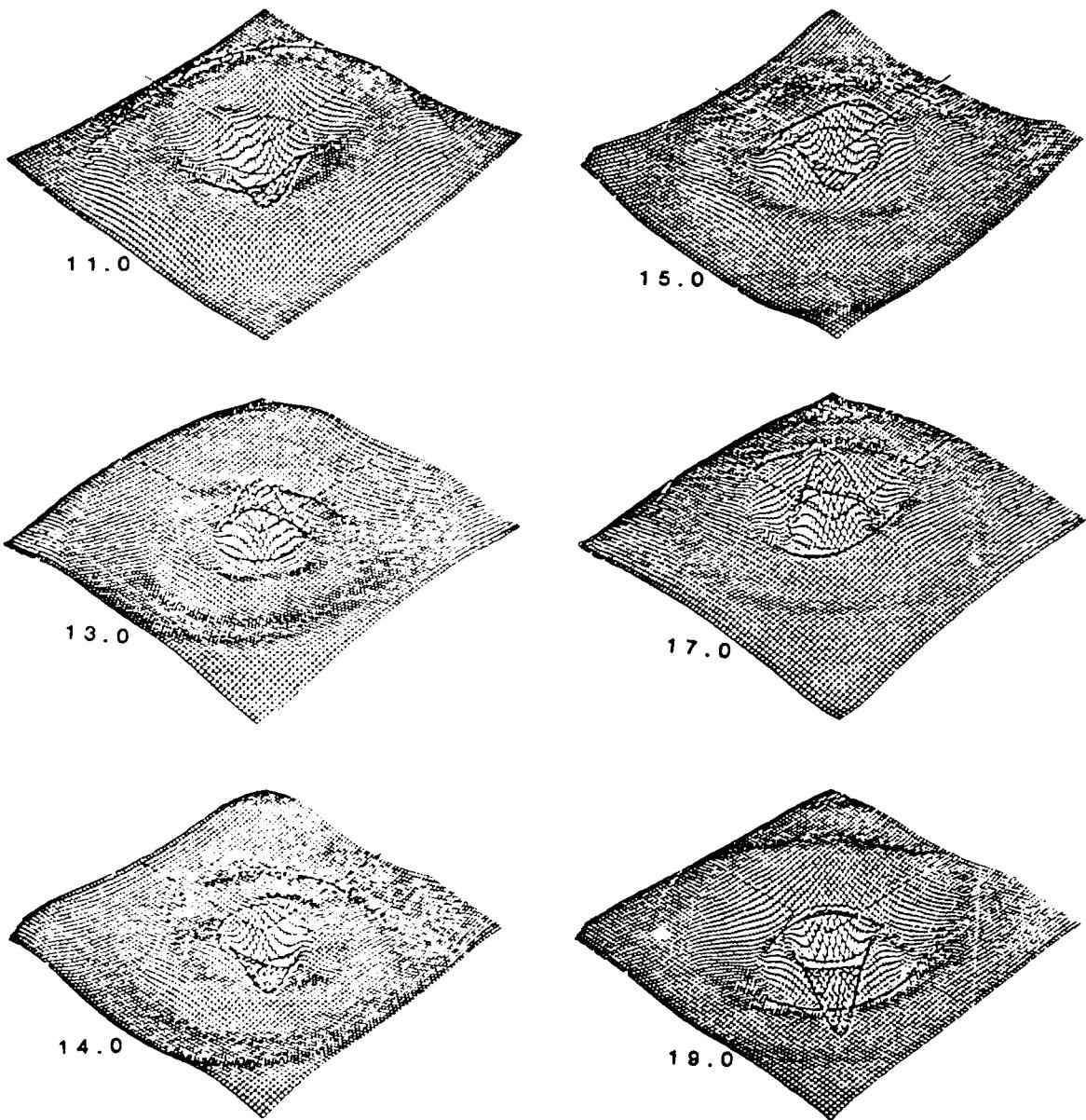


Figure 19 Diffracted waves from semisubmerged sphere,  
regular unidirectional waves,  $k=1.4$ .  
 $T=11-19$  seconds.

that there is some problem associated with both forward speed and cases with shapes more closely representing a slender ship. The reasons for these "blow-ups" could not be readily identified.

### 3.7 LIMITATIONS, RUN TIMES AND COMPUTATIONAL REQUIREMENTS

#### Theoretical and Numerical Limitations

- (1) The limitations of strip theory generally apply.
- (2) The limitations of linear wave theory apply.
- (3) The limitations of linearized hydrodynamic formulations (linearized free surface, separation of potentials, linearized Bernoulli equation, etc.) apply.
- (4) Strip theory formulations here do not include terms related to the spatial derivative of damping coefficients (as found in "extended" SCORES).
- (5) Flare force is computed using the relative free surface velocity in contrast to using a component of average subsurface wave velocity. Furthermore, free surface distortion effects are not included (diffractions, "pile-up," etc.).
- (6) The ambient wave system for the three-dimensional analysis is formulated for unidirectional waves only.
- (7) The P, E and X source influences matrices are computed only for the mean hull position in the present formulation. Details of the computation are presented in Volume II of this report.
- (8) The use of either a pre-selected or time-varying estimate of added mass and damping coefficients for the ship motion-induced forces in irregular waves is an approximation.
- (9) Pitch angle must not become large enough to cause the intersection of a station plane and the sea surface so that multiple regions or a closed contour in the station plane is defined [3].

#### Run Times

Typical run times for several simulations with strip theory derived forces and three-dimensionally derived forces are shown in Table 4 for a VAX 11/750 without a floating point processor.

It is estimated that reductions in run time by a factor of 5-10 would occur with any of the large mainframe CDC machines; and a reduction by a factor of 15-20 would occur with a supercomputer (CRAY or similar). It should be emphasized that the program is expensive to run, regardless of the type of machine on which it is installed.

Table 4

SIMULATION OF .....	VAX 11/750 CPU TIME
Motion and Hull Girder Response of 25-station ship in one regular wave. Steady state evaluated after 2 minutes real time with $\Delta t = 0.5$ sec.	1200 CPU seconds
Motion and Hull Girder Response of 25 station ship in irregular wave system of 10 components evaluated after 10 minutes of real time simulation. $\Delta t = 0.5$ sec.	16 CPU hours
Pressure prediction only of 120 panel body for 15 seconds real time $\Delta t = 0.1$ sec.	17 CPU hours

Computational Requirements

The computer programs were developed on a DEC VAX 11/750. The peak working set size was 250. The memory requirement for the completely integrated program (2D plus 3D) is 650K bytes. When the 3D subroutines are not used and only 2D simulations are used, the memory requirement is 250K bytes.

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#### 4.0 CONCLUSIONS AND RECOMMENDATIONS

A numerical method for the simulation of ship motions, hull girder loads and transient three-dimensional hydrodynamic pressures has been developed. The result is a computer program that is capable of evaluating nonlinear responses of surface ships associated with large amplitude motions. The fundamental limitation of the approach is the use of linear wave theory. The restrictions on the severity of the sea conditions that this limitation imposes is not yet known, although it is believed that the method would be appropriate for evaluating motions and hull girder loads in moderately severe sea states.

Furthermore, the three-dimensional technique developed is capable of predicting transient hydrodynamic pressures on time-varying hull shapes moving with arbitrary motions and forward speed. Further effort is required to fully realize these capabilities. An outline of the suggested work is given in the next section.

Although the method presented here and the associated computer program need additional attention to advance them from the investigative and developmental stage at which they now are, some progress has been made toward a more advanced method for ship motion and wave load prediction. There presently exists no other program for the time domain simulation of ship motions and loads in six degrees of freedom for a full range of headings. Nor is there any other program capable of predicting three-dimensional distributed hydrodynamic pressures in the time domain for arbitrary ship motions in waves.

The CAPSIZE program [3,29] and the NSUP program [6] which were used as starting points for the present method have been extended or modified in the following principal ways:

- Actual strip theory formulation used for hydrodynamic forces instead of simplified and approximate methods for added mass, damping and wave exciting forces
- Hull girder loading prediction added, including "flare force" effect
- The addition of the incident wave potential into the three-dimensional formulation
- A number of computational and numerical changes associated with the calculation of two-dimensional hydrodynamic coefficients, the evaluation of two-dimensional hydrodynamic forces, and the evaluation of pressure in the wave above the still water level.

The bulk of the effort in this project was committed to the concept development of a suitable method and the development and testing of the computer code. Because of the particularly time-consuming nature of debugging and testing simulation programs, the extent of the validation effort has been limited to the minimum number of runs needed to verify the capabilities of the

computer programs and evaluate the basic theory and numerical techniques when possible. A full and extensive validation of the methods and codes would require the type of test program typically associated with actual (physical) model testing, with a level of effort representative of a major project in itself. An outline of a simulator test program is provided in Appendix A as a possible basis for the same type of studies reported in SSC-246\* [40] and SSC-271\*\* [41] to validate and further investigate SCORES after its initial development.

#### Recommendations

The work presented herein represents an initial level of investigation and development. The numerical methods and computer programs require further testing, validation and improvement. The following list of recommendations indicates areas where further effort is required or desirable in the near-term, mid-term or far-term.

#### Near-Term

1. A comprehensive test and validation program is required, an outline of which is given in Appendix A for the two-dimensional method.
2. The method or program coding for the computation of Froude-Krylov forces or strip-theory derived forces should be corrected or improved to provide better predictions, specifically heave motion.
3. The numerical methods and coding associated with the three-dimensional technique should be improved. Specifically, the following areas will be investigated and modified or improved:
  - (a) Investigate the method used for computing the source panel velocity array and the source potential influence array. The so-called exact method of Smith and Hess might be improved. More efficient methods might also be incorporated. There may be reason to suspect that the problems with the ellipsoid tests attempted are due to numerical problems in this area.
  - (b) Investigate the theoretical formulations that include some forward speed effects. Investigate the numerical/computational representation of the theory. Check the coding dealing with forward speed aspects. Identify any deficiencies and make the appropriate changes and additions.

\* Kaplan, P., et al, "Theoretical Estimates of Wave Loads on the SL-7 Containership in Regular and Irregular Waves," SSC-246, 1974.

\*\* Kaplan, P., et al, "A Correlation Study of SL-7 Containership Loads and Motions - Model Tests and Computer Simulations," SSC-271, 1977.

- (c) Examine the feasibility and necessity of applying a different free-surface condition interior to the hull. As Chapman suggested in [6], instead of using the linearized free-surface condition over the entire free surface, the surface elevation interior to the hull can be constrained to be uniformly zero by placing surface panels over this region. This would suppress standing waves which are excited in the hull interior as a by-product of the potential flow method of simulation.
- (d) Investigate more efficient ways of computing. For example, if we can assume that motions are sufficiently small, then certain values which are functions, sums and products of the various source influence arrays might be precomputed and stored, rather than computing them inside computational loops over  $k_x$  and  $k_y$  wave numbers for each panel.
- (e) Demonstrate the accuracy and capabilities of the program by comparing numerical results with predictions from theory or other programs for various shapes at zero speed (sphere, ellipsoids, barge shape, ship shape) and for those shapes with forward speed. The basis for these comparisons would be added mass, damping and wave excitation coefficients.
- (f) Carry out sufficient testing to develop an experience base for setting the parameters for the spectral wave representation.
- (g) Investigate and demonstrate the ability of the method to properly predict the distributed hydrodynamic loads on the underwater hull.
- (h) Examine the feasibility and identify the numerical techniques that would allow for the underwater hull form to change with time.

Mid-Term

- 4. Appropriate specific methods to predict slamming loads and green water loads should be investigated and incorporated in the present program.
- 5. An advanced statistical processing routine should be incorporated in the program to derive frequency response spectra, as well as probability density functions and cumulative distributions of maxima and minima.
- 6. A method should be investigated and appropriate subroutines incorporated to structurally model the ship hull girder in order to predict transient non-rigid body response.
- 7. Improved coding for the computation of sectional mass distribution properties should be written.
- 8. Coding for the computation of appendage damping should be written.

Far-Term

9. Linear wave theory was assumed for the present model and is consistent with the linearized free-surface formulations associated with strip theory and the three-dimensional method. It may be worthwhile, however, to pursue the use of a nonlinear wave theory to generate large amplitude deterministic unidirectional waves. Although the nonlinear wave could not be applied, in a strict sense, within the hydrodynamic formulations as they exist in the two- and three-dimensional formulations, they could be accounted for in an approximate way. Hydrostatic and dynamic buoyancy forces could be accounted for "exactly." Ship motion-induced hydrodynamic forces could be approximated as they are in the present version. Diffraction forces could be possibly estimated by using the same method as now exists but representing the nonlinear wave in the vicinity of the ship with a similarly proportioned linear wave. For the transient pressure simulation, the exact nonlinear wave kinematics could be used to prescribe part of the body boundary condition at the center of each panel.
10. The use of the impulse response function and convolution integral to predict ship motion-induced damping forces should be investigated and appropriate subroutine(s) included in the present version. This would be a partial alternative for the "characteristic frequency" scheme now in place.

The efforts listed under each of the above categories can be grouped into the three separate projects with the following approximate level of effort suggested:

Near-Term Project	3000 manhours
Mid-Term Project	2000 manhours
Far-Term Project	2000 manhours

The near-term project should be considered a necessary requirement in order that the methods and computer programs initiated here are sufficiently developed and proven for practical use.

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APPENDIX A  
NUMERICAL SIMULATOR TEST PROGRAM

**1.0    OBJECTIVE**

The objective is to fully exercise the computer program SSX, using as a test vehicle a ship for which model tests have been carried out for a range of headings, speeds and wave heights, with emphasis on lower speeds and higher wave heights.

**2.0    TEST SERIES**

**2.1 TEST SERIES A - REGULAR WAVE TESTS**

The ship is subjected to unit amplitude unidirectional regular waves at five headings, four Froude numbers, and at six frequencies corresponding to various wavelength/ship-length ratios. The critical parameters are:

<u>Wavelength Parameters</u> ( $\lambda/L$ )	0.5, 0.75, 1.0, 1.25, 1.5, 2.0 (or equivalent at other headings)
<u>Froude Numbers</u> ( $F_n$ )	0.0, 0.05, 0.10, 0.15
<u>Headings</u> ( $\beta$ )	180, 135, 90, 45, 0
<u>Measurements</u>	- (a) C.G. Motions (b) Midships Hull Girder Loads (c) Sectional Forces Including Hydrostatic, Froude-Krylov, Wave Exciting and Ship Motion Induced Forces
<u>Total Number of Runs</u>	120

**2.2 TEST SERIES B - LINEARITY CHECKS (NO FLARE FORCE)**

The ship is subjected to unidirectional regular waves of four different heights, six frequencies, two speeds and five headings. The critical parameters are:

<u>Wave Height</u> ( $H_w$ )	0.2D, 0.4D, 0.6D, 0.8D (Where D is Ship Depth)
<u>Wavelength Parameters</u> ( $\lambda/L$ )	0.5, 0.75, 1.0, 1.25, 1.5 (With the Constraint $H/\lambda < .1$ )

<u>Froude Numbers</u> ( $F_n$ )	0.0, 0.10
<u>Headings</u>	180, 135, 90, 45, 0
<u>Measurements</u>	(a) C.G. Motions (b) Midships Hull Girder Loads
<u>Total Number of Runs</u>	200

### 2.3 TEST SERIES C - LINEARITY CHECK WITH FLARE FORCE INCLUDED

The ship is subjected to unidirectional regular waves in head and following directions, three speeds and five frequencies and four wave heights. The critical parameters are:

<u>Wavelength Parameters</u> ( $\lambda/L$ )	0.5, 0.75, 1.0, 1.25, 1.5
<u>Froude Numbers</u> ( $F_n$ )	0.0, 0.10, 0.15
<u>Headings</u>	180, 0
<u>Wave Heights</u>	0.2D, 0.4D, 0.6D, 0.8D
<u>Measurements Taken</u>	(a) C.G. Motions (b) Midships Hull Girder Loads (c) Sectional Forces
<u>Total Number of Runs</u>	120

### 2.4 TEST SERIES D - LINEARITY CHECK WITH DRAFT-DEPENDENT HYDRODYNAMIC COEFFICIENT SELECTION

The ship is subjected to unidirectional regular waves of four different heights, six frequencies, two speeds and three headings. The critical parameters are:

<u>Wave Height</u>	0.2D, 0.4D, 0.6D, 0.8D
<u>Wavelength Parameters</u>	0.5, 0.75, 1.0, 1.25, 1.5, 2.0
<u>Froude Numbers</u>	0.0, 0.10
<u>Headings</u>	180, 135, 90
<u>Measurements</u>	(a) C.G. Motions (b) Midships Hull Girder Loads (c) Sectional Forces
<u>Total Number of Runs</u>	144

## 2.5 TEST SERIES E - IRREGULAR WAVE TESTS

The ship is subjected to four unidirectional irregular systems with frequency spectra corresponding to a two-parameter Bretschneider formulation, one speed, five headings. The critical parameters are:

<u>Significant Wave Heights (<math>H_s</math>)</u>	10, 20, 30, 40 ft.
<u>Spectral Modal Frequencies</u>	Most Probable
<u>Headings</u>	180, 135, 90, 45, 0
<u>Froude Number</u>	0.10
<u>Measurements Taken</u>	(a) C.G. Motion Statistics (b) Midship Hull Girder Load Statistics
<u>Total Number of Runs</u>	20

In Test Series E, the frequency at which the 2-D hydrodynamic coefficients are selected is fixed according to the peak of the response spectra obtained from a linear frequency domain analysis.

## 2.6 TEST SERIES F - IRREGULAR WAVE TESTS WITH DRAFT-DEPENDENT HYDRODYNAMIC COEFFICIENT SELECTION

The ship is subjected to three unidirectional wave systems, one speed, three headings. Two-dimensional coefficients are selected as a function of instantaneous sectional draft. The critical parameters are:

<u>Significant Wave Heights (<math>H_s</math>)</u>	20, 30, 40
<u>Headings</u>	180, 135, 90
<u>Froude Number</u>	0.10
<u>Measurements Taken</u>	(a) C.G. Motion Statistics (b) Midship Hull Girder Load Statistics
<u>Total Number of Runs</u>	6

For Test Series F, the ship motion hydrodynamic coefficients are selected as with Test Series E.

## 2.7 TEST SERIES G - IRREGULAR WAVE TEST: (WITH VARYING FREQUENCY)

Same as Test Series D, except the 2-D hydrodynamic coefficients associated with ship motion-induced forces are selected according to the most recent measured zero crossing periods of motion.

<u>Additional Measurement Taken</u>	Automatically - Selected Frequencies Used for Heave, Sway and Roll 2-D Coefficients
<u>Total Number of Runs</u>	20

## 3.0 SCOPE OF WORK

The following table is used to estimate computer costs using a VAX 11/750 with below average rates:

<u>Test Series</u>	<u>No. Runs</u>	<u>CPU Hours Per Run</u>	<u>Subtotal Hours</u>
A	120	1	120
B	200	1	200
C	120	1	120
D	144	1	144
E	20	32	640
F	6	32	192
G	20	32	640
			2056 CPU HOURS

If we assume a rate for CPU time on a commercial VAX 11/750 is at least \$60/CPU Hour, the total computer charge would be at least \$123,360.00. There are also a significant amount of manhours involved in preparing the input data. Analyses and evaluation of the resultant data would also require at least 1000 manhours.

Even if the number of runs could be reduced by half, a full set of validation runs for SSX requires a surprisingly large amount of effort and computational resources.

**ADVANCED METHODS FOR  
SHIP MOTION AND WAVE  
LOAD PREDICTION**

**VOLUME 2**

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APPENDIX A

## 1. INTRODUCTION

Program SSC performs a time-domain simulation of ship motions, hull girder loads and distributed pressures. Two preprocessing programs - HYDREX2 and HYDREX3 - perform certain calculations in preparation for a simulation. Program HYDREX2 computes two-dimensional sectional hydrodynamic coefficients and HYDREX3 calculates several arrays associated with the three-dimensional source representation of the hull. Program input includes a description of the ship's hull by sectional offsets, representation of the hull by quadrilateral or triangular panels, ship geometric and inertial particulars, operational and environmental specifications, and simulation parameters and job options. Output includes a time history plus statistical summaries of heave, pitch, sway, roll, yaw, vertical and horizontal shear and bending moments, torsional moments and dynamic pressures at centers of hull surface panels. The present version of the program contains several features to facilitate experiments with alternative techniques. The program SSX can be run in a batch or interactive mode. The three programs are written in FORTRAN 77 and developed on a DEC VAX 11/750 computer.

This volume (Volume II) provides instructions to the user for performing computations with SSX, HYDREX2 and HYDREX3. A technical description of the model formulation and solution procedures are provided in Volume I.

Program structure and computational overview is first given in Section 2. Program software specifications are described in Section 3. Run procedures are given in Section 4 with input and output variable descriptions. A sample case in Section 5 illustrates code application. Program listings are contained in Appendix A.

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## 2. GENERAL STRUCTURE AND COMPUTATIONAL OVERVIEW

A simplified schematic of the basic flow of information is provided in Figure 1. It shows the major sequence of information processing. Three data files are initially required. The basic information file [BIF] contains basic geometric and mass properties of the ship, operational and environmental parameters, and calculation specifications, simulation parameters and job options. The ship offset file [OFF] gives station offset data. The hull panel file [PAN] contains nodal points and connectivity relationships to represent the hull surface by quadrilateral and/or triangular panels.

Program HYDREX2 uses the [BIF] file and [OFF] file to calculate two-dimensional hydrodynamic added mass and damping coefficients using the Frank Close-Fit method. HYDREX2 places the results of its computation in a two-dimensional coefficient file [COF]. It also provides a printout of its results.

Program HYDREX3 uses the [PAN] file to compute panel center coordinates, areas, normals, source density matrix [E], panel pressure matrix [PP] and forward velocity pressure matrix [PX]. The results are placed in a data file [MAT]. HYDREX3 need not be run if it is anticipated that distributed pressures will not be required.

Program SSX uses the [BIF] data file, the [COF] data file, the [MAT] data file (if a pressure distribution is desired), and the [OFF] data file. SSX output includes an input data summary, time domain results and response statistics.

A simplified flow schematic of the SSX program is given in Figure 2. The main program routine SSX initially asks for the names of the [BIF], [OFF], [COF] and [MAT] data files. Subroutine READIN is called to load the necessary variables and arrays using data read in from the four data files.

At this point all data has been entered, and subroutine PREPARE is called to initialize certain arrays and perform some computations in preparation for the simulation. Next, subroutine COFFEE is called to load a set of arrays that contain the initial set of two-dimensional hydrodynamic coefficients associated with the mean still water draft, the frequencies of encounter of the wave components and the predicted characteristic frequencies of ship motion.

The program then calls FOLIO1 to display the basic input data and some computed preparatory information. At the option of the user, subroutine OUTCOF can be called to display the initial set of two-dimensional hydrodynamic characteristics.

Now the actual simulation is ready to begin. At each time step, the subroutine FOLIO2 is called to display motion and loads response values for that time. Thus FOLIO2 is initially called at  $t = 0$ . The program then proceeds with the simulation. Within the time step loop in the main program, three subroutines are called - RK4, HULL and PRESSURE. The subroutine RK4 sets up and solves the equations of motions, the subroutine HULL evaluates hull girder loads, and the subroutine PRESSURE evaluates dynamic pressure at the center of each hull surface panel. PRESSURE is only called for a user-selected period of time within the simulation. Both the RK4 and PRESSURE subroutines lead into the large number of subroutines which will be described in the next two paragraphs. At the end of each time step, the time is compared to the user specified stop time. The loop is updated if the stop time has not been reached. If it has been, the simulation stops, and subroutine FINI is called to provide summary statistics.

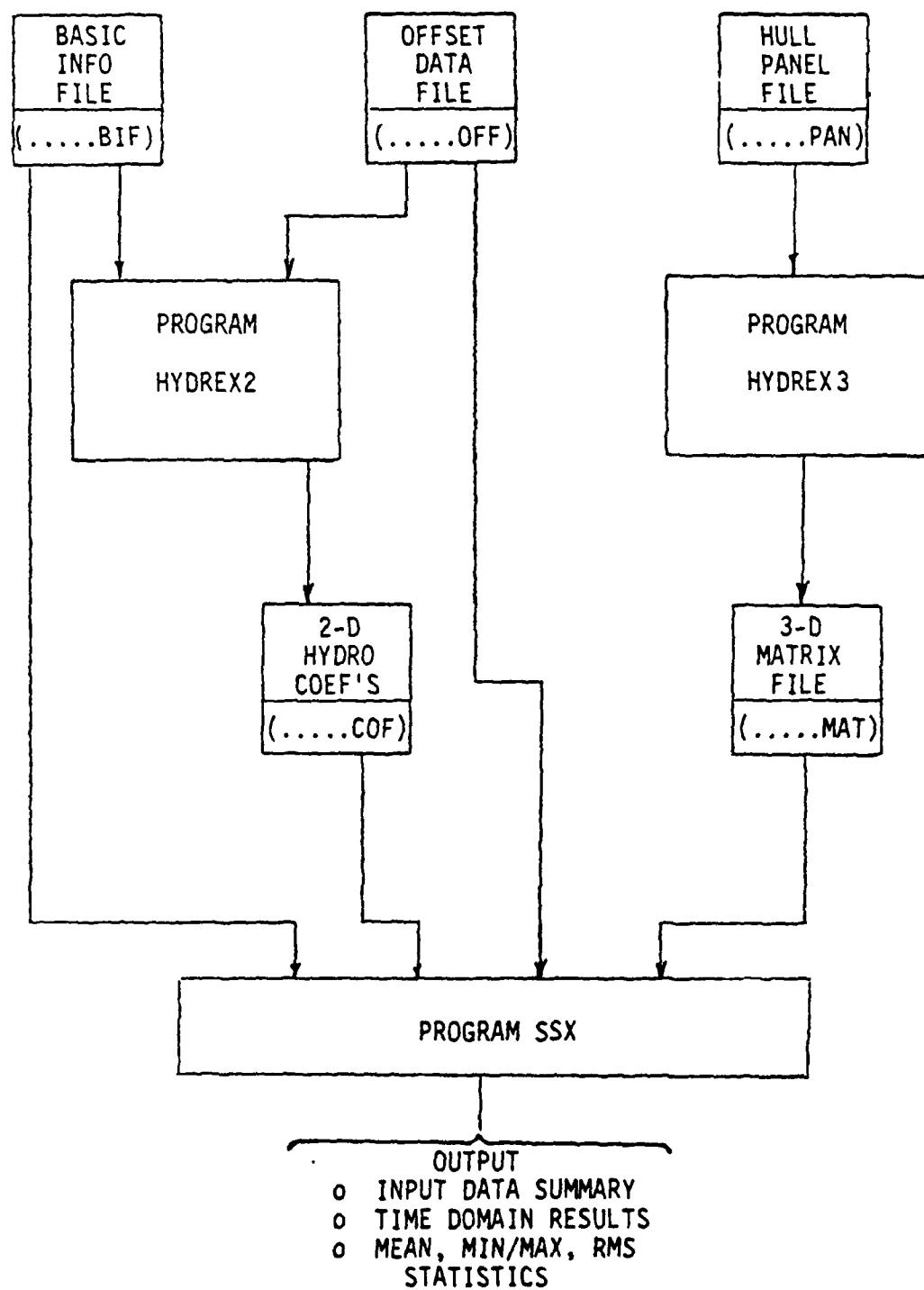
Figure 3 provides a simplified representation of the computational process associated with the solution of the equations of motion. The subroutine RK4 calls DERIV four times for each time step according to the fourth order Runge-Kutta scheme. The subroutine DERIV sets up the equations of motion in the form of four first order ordinary differential equations. It evaluates the derivatives to be integrated by RK4. The subroutine DERIV calls subroutine FORTIS to evaluate external forces and moments, which include hydrostatic and hydrodynamic forces calculated by subroutine AQUA2D. The

subroutine AQUA2D calls a number of other supporting subroutines and functions. MOCHA evaluates 2-D hydrodynamic coefficients when they are to be a function of sectional draft and/or ship motion characteristic frequencies. KRYLOV evaluates ponential and trigonometric integrals for each section. Functions ETAF and ETABAR evaluate the wave surface elevation.

The computational process associated with hull surface pressure calculations is provided in Figure 4. Subroutine PRESSURE calls ACPTR which computes the pressures and normal acceleration at panel centers induced by the free surface. Next subroutine ZBLACN determines the relative normal acceleration at each panel by subtracting the free surface induced accelerations and incident wave field accelerations from the hull kinematical acceleration. The time derivative of panel source strengths are also evaluated in ZBLACN. Next, subroutine POTB is called to obtain body-induced pressures. The body-induced pressure is added to the free-surface-induced pressure at each panel. The final subroutine is CFSR which advances the free surface representation in preparation for the next time step.

If subroutines to evaluate bottom slamming and green water loads were to be included in later modifications to the program SSX, they should be called from the subroutine AQUA2D. Any force as a function of time, displacement velocity and position on the ship can be evaluated from the information available at any instant within AQUA2D.

FIGURE 1  
BASIC INFORMATION FLOW



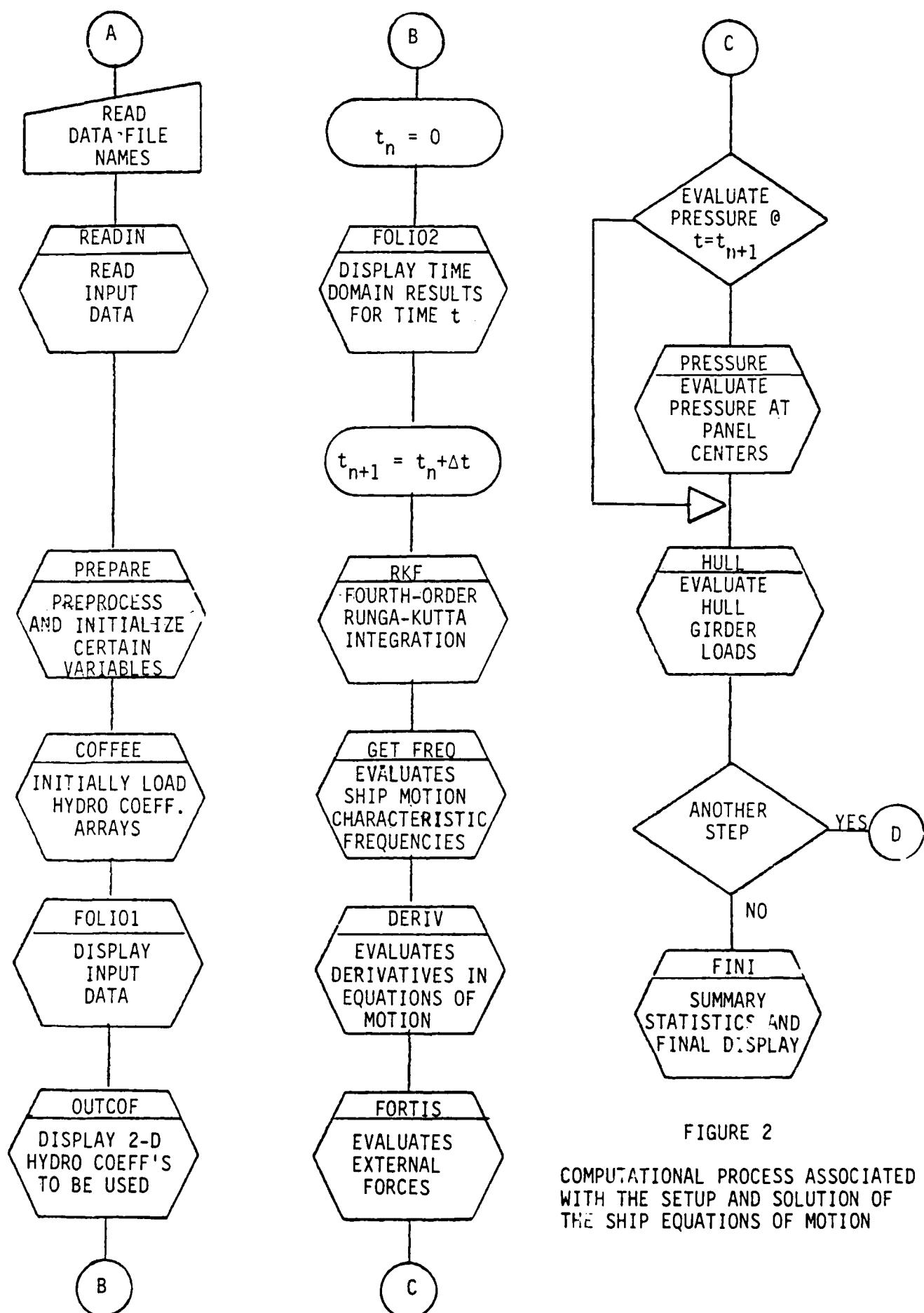


FIGURE 2

COMPUTATIONAL PROCESS ASSOCIATED WITH THE SETUP AND SOLUTION OF THE SHIP EQUATIONS OF MOTION

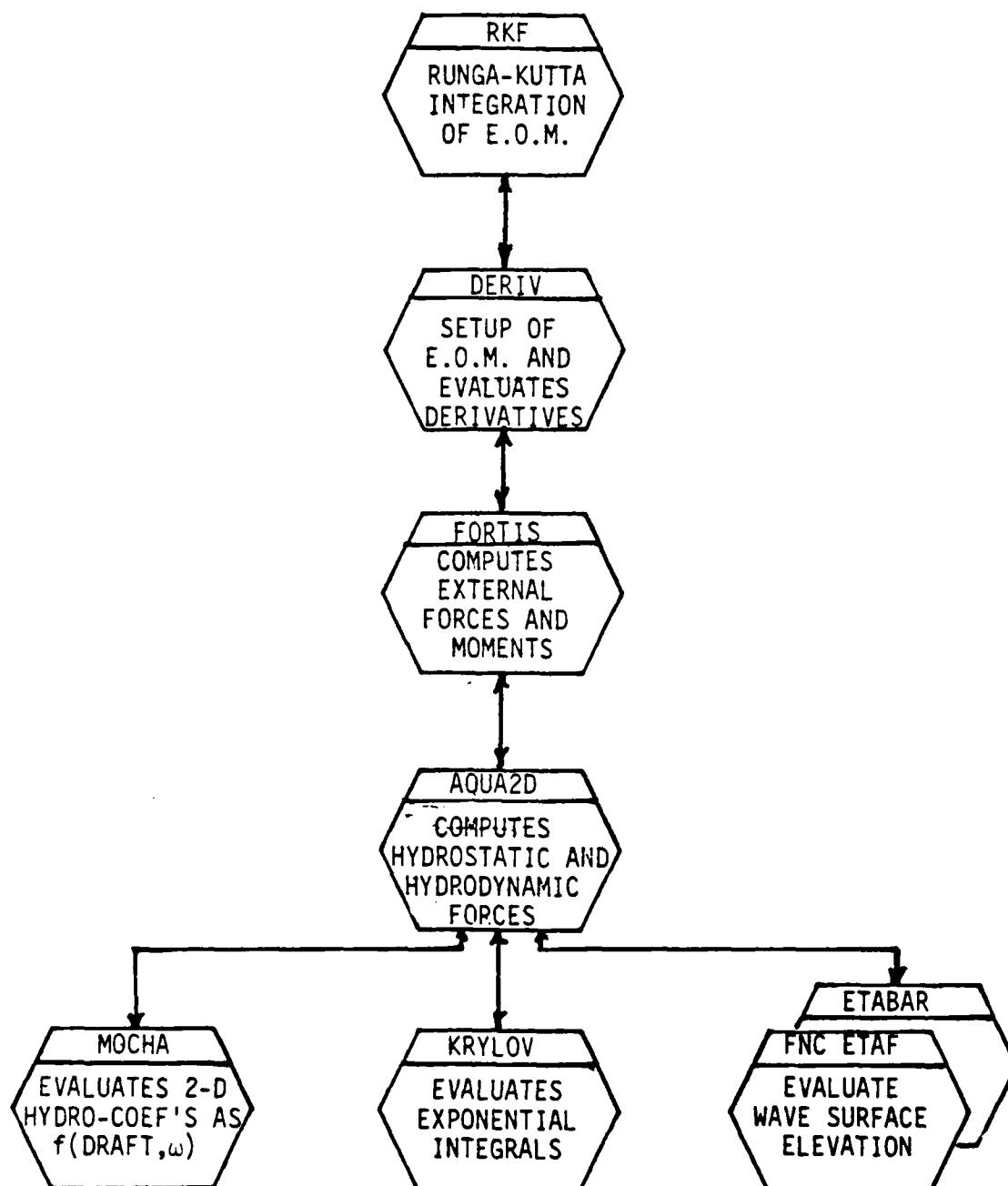


FIGURE 3

COMPUTATIONAL PROCESS ASSOCIATED WITH  
THE SETUP AND SOLUTION OF THE SHIP  
EQUATIONS OF MOTION

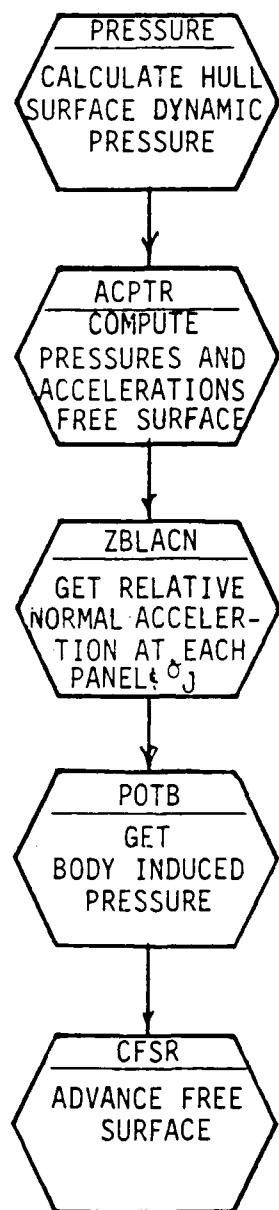


FIGURE 4  
COMPUTATIONAL PROCESS ASSOCIATED WITH HULL  
PRESSURE CALCULATIONS

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### 3. GENERAL SOFTWARE SPECIFICATIONS

The three codes conform to ANSI X3.9-1978 FORTRAN 77. They were developed on a Digital Equipment Corporation VAX 11/750 computer with a working set size of 250 pages. The only obvious machine depending coding are OPEN statements to open and assign files.

Rather than completely developing new codes, two previously developed and tested codes were used as a basis for the present three codes. The CAPSIZE program written at the University of California, Berkeley by Paul Wood was used as a starting point. The basic variable assignments used in that program were retained, as was the basic computational scheme for the equations of motion. For the three dimensional pressure computations, a program developed by R.B. Chapman entitled NSUP was used as a starting point. Some of the subroutines contained in NSUP and CAPSIZE were adopted directly, while others were completely rewritten. A number of new subroutines were written as well.

## SSX Subroutines

The following is a list of subroutines and functions used in the SSX. Short descriptions are given here and the more complicated subroutines should be sufficiently well documented internally to clearly illustrate the computational process.

MAIN	The purpose of the main program is to accept data file names, open the appropriate files, read input data, call several subroutines to prepare data for the simulation, and then execute the time step loop which calls the several subroutines which perform the simulation of motion, hull girder loads and hull dynamic pressures. Calls READIN, SETUP, PREPARE, COFFEE, FOLI01, OUTCOF, FOLI02, RK4, HULL, PRESSURE and FINI.
READIN	Reads data from the basic information file [BIF], the ship offset file [OFF], the sectional hydrodynamic coefficient file [COF] and the panel pressure matrices file [MAT]. Prints an echo of data read from [BIF]. Called from MAIN.
PREPARE	Performs computations in preparation for simulation, including (a) from given offsets on the port side, assigns symmetrical offsets on starboard side, (b) recomputes offset coordinates relative to center of mass, (c) consolidates fore and aft profile coordinates into a single pair of arrays, (d) loads certain sectional mass arrays and generalized mass matrix. (e) computes wave numbers, (f) converts initial data in degrees to radians, (g) converts initial linear velocities from ship coordinates to fixed coordinates, and (h) divides all sectional hydrodynamic coefficients by fluid density, (i) initializes special free surface representation for pressure calculations. Calls AFSR. Called from MAIN.

ROTATE	Sets up coordinate system rotation matrices. Called from PREPARE, FORTIS.
FOLI01	Displays ship motion response and hull girder loading response values for each time step. Also accumulates data for post simulation statistical analysis. Called from MAIN.
DERIV	Evaluates the right hand side of the equations of motion. These values are the ones integrated by the integration scheme. Causes external forces to be calculated, combined with inertial properties to yield translational and angular momentum in the appropriate coordinate systems for solution using Newton's second law. Called from RK4. Calls FORTIS.
FINI	Prints final execution and response value statistics - including mean, rms, maximum and minimum.
RK4	Fourth-order Runge-Kutta integration subroutine. Integrates an array YYDOT containing rotational and translational velocities and accelerations to yield array YY which contains new displacements and velocities. Called from MAIN. Calls DERIV.
ERROR	Subroutine to display a limited amount of diagnostics in the event of a runtime error, principally due to data input errors.
KRYLOV	Evaluates two-dimensional exponential and trigonometric integrals over each station of the ship. Called from AQUA2D.
COFFEE	Performs two-dimensional linear interpolation in the table of sectional hydrodynamic coefficients. Coefficients are selected for the mean design draft, and at encounter

frequencies associated with each wave component and at "characteristic" frequencies of ship motion initially assumed to be the modal frequency of the sea spectrum if irregular waves are imposed.

- FXIF Provides an index (IT) and a multiplier (TX) for linear interpolation for draft in the table of sectional hydrodynamic coefficients.
- TXIT Provides an index (TX) and a multiplier (IT) for linear interpolation for frequency in the table of sectional hydrodynamic coefficients.
- FUNCTION COX Performs the two-way linear interpolation in the table of sectional hydrodynamic coefficients using IF, FX, IT, TX obtained through FXIF and TXIT.
- FUNCTION CODXP Same as CODX except it uses sectional hydrodynamic coefficients that have not been divided by sectional area, and determines the x-spatial derivative.
- FUNCTION ETABAR Provides the wave elevation in fixed coordinate system above a given point of the ship's centerline along hull, stern and transom.
- FUNCTION ETAF Provides the coordinate of the water surface in yawed and pitched coordinates given a section number, distance off the centerline and relative displacement of the section.
- GETFREQ Evaluates the average of the two most recent zero crossing periods and calculates characteristic frequencies of ship motion in heave, sway and roll. Called from RKA.
- OUTCOF Prints the temporary sectional hydrodynamic coefficients currently in arrays in COMMON/COEFFX/. Normally done only at the beginning of the simulation. Called from MAIN.

FOLI01	Displays or prints a summary of basic input data. Called from MAIN.
FOLI02	Displays or prints ship motion and hull girder response. Called from MAIN.
FOLI03	Displays or prints ship hull pressure reponse. Called from MAIN.
TBAR	Provides the average depth of immersion of a given section.
SPECTRA	Provides the amplitude and frequency of ten wave components derived from a two parameter Bretschneider spectrum. Called from SETUP.
PRESSURE	Provides values of dynamic pressure at the center of each hull panel for a particular instant of time. Called from MAIN. Calls ACPTR, ZBLACN, POTB and CFSR.
ZBLACN	In the pressure computations, applies the specified body accelerations for the six degrees of freedom to compute the resulting normal accelerations at the panel centers. The free-surface induced normal accelerations ACNW(J) are subtracted to obtain the net normal acceleration at each panel center, ACN(J), of the body relative to the fluid. These accelerations must be cancelled by the time derivative of the body source density distribution, ST(K). The ACN(J) vector is multiplied by he E matrix to get the necessary net rate of change of the panel source densities, ST(K). The total source strength densities are accumulated in STOLD(K). Called by PRESSURE.

ACPTR	In the pressure computations computes free-surface induced accelerations ACNW(J) and pressures PRFS(T) at panel centers. Called by PRESSURL.
POTB	In the pressure computations this subroutine is used to compute the generalized body-induced pressure BPRES generated by a known source strength distribution and its time derivative. The matrix P(J,K) is multiplied by a vector, ST(K), representing the time derivative of source densities of the panels. Similarly the term proportional to forward speed is computed from the matrix PX and a vector representing the accumulated source densities, STOLD(K). Called by PRESSURE.
CFSR	In the pressure computations advances free-surface by one time increment. Moves body relative to the free surface. Adds the changes in free-surface elevation induced by the body sources acting over the time increment to the free-surface representation. Second order effects in time are included.
AFSR	In the pressure computations sets up and initializes the free-surface representation called by PREPARE.

#### HYDREX2 Subroutines

The following is a list of subroutines in HYDREX2.

MAIN	Accepts data file names, opens the appropriate files, reads input data, loops over six drafts, calling FLOAT and HYDRO within the loops. Also calls INDATA to read in data from files.
------	--

FLOAT            "Floats" the ship at the specified draft. Creates a set of "wet" offsets to be used for hydrostatic calculations and for the computation of sectional hydrodynamic coefficients.

HYDRO          Applies the Frank Close-fit method to "wet" offsets. Adopted from CAPSIZE which adopted it with some modifications from the original NSRDC code. HYDRO calls GIRL, BEER, WINE and STATN.

STATN         Revises the station offsets by inserting additional points in order to optimize the hydrodynamic computations and to suppress anomalous behaviour which sometimes occurs at certain "singular frequencies". INSERT is called by STATN as part of this process.

GIRL           Computes certain frequency-independent coefficients which are used in the two-dimensional hydrodynamic computations.

BEER           Computes the two-dimensional hydrodynamic coefficients for the special cases of zero or infinite frequency. It calls the simultaneous linear equation solver LINEQT.

WINE           Performs the computation of the two-dimensional hydrodynamic coefficients for finite nonzero frequencies, calling several subroutines for special operations. WOMEN computes some of the interaction between segments of the section. SONG performs the integration of pressures around the section. ROMEO evaluates the exponential integral with complex argument. JULIET is a simultaneous linear equation solver for certain sets of equations in HYDRO.

## HYDREX3 Subroutines

The following routines are contained in the program HYDREX3.

- |       |  |
|-------|--|
| MAIN  | Reads input data and calls subroutines EBD and POTST.  |
| EBD   | This subroutine reads in the (x,y,z) coordinates of each of the four corner points into a set of arrays XPT(N), YPT(N), ZPT(N). Panels are identified by a set of four integers giving the array positions of the four corner points of each panel. Panel areas, normals and center point coordinates are then computed. Finally, the E matrix giving the source time derivative distribution for a set of prescribed normal accelerations is computed. The inverse of E is computed first by the subroutine GE which gives the acceleration induced at any panel center point, J, by a uniformly distributed time derivative of source strength density of unit magnitude acting over any surface of panel, JL. Subroutine MATIN inverts E to obtain the desired form. Simultaneously, the matrix PX which gives the x component of velocity at the center of panel J induced by a source strength of unit magnitude distributed over a panel, JL, is computed. |
| POTST | Calculates the matrix P(N,J) giving the net force or moment for the Jth degree of freedom induced by a unit time derivative of source strength over panel N. Fundamental to this is the need to compute the potential integrated over each panel area due to a uniform source density over every other panel. For panels which are far apart relative to their dimensions this value is, for unit source density, simply proportional to the product of their areas divided by the distance between centers. The method used here is to divide each panel into a large number of small subpanels and then calculate the results numerically, adding the contributions of each subpanel.  |

under the assumption that their separations are large relative to their dimensions.

SELF            This subroutine is called POTST to compute diagonal terms in the P matrix.

MATIN          The matrix inversion routine used by subroutine EBD to invert matrix E.

GE              A subroutine called by EBD to compute the elements of matrix E prior to inversion. It computes the velocity (acceleration) at field point (XF, YF, ZF) induced by a source density (time rate of change of source strength) of value unity distributed uniformly over panel J.

GO              A subroutine called by GE.

SOLID          Also called by subroutine GE to compute the solid angle of a panel relative to the field point.

PREP          Prepares all panels for the GE subroutine. It is called by EDB prior to using GE.

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#### 4. RUN PROCEDURES

This section presents the procedures involved with running HYDREX2, HYDREX3 and SSX. It also gives input data description and formats.

##### 4.1 PROGRAM HYDREX2

HYDREX2 calculates two-dimensional sectional added mass and damping coefficients using the Frank Close-fit method. Two data files are required - a [BIF] file which contains basic ship and program run information and the [OFF] file which contains the ship's offsets. The program will create a third file [COF] into which it will write the results of its calculations.

When HYDREX2 is run, the only required input is the following three files names:

<u>File Name</u>	<u>Format</u>
Basic Input File	(A)*
Ship Offset File	(A)
2-D Coefficient File	(A)

Descriptions of the [BIF] and [OFF] file are given in the next two sections.

##### Basic Information File [BIF]

The basic information file is used for programs HYDREX3 and SSX as well as HYDREX2. The full [BIF] file will contain more information than that which is described below. However, to run HYDREX2, only the first part of the [BIF] file need be created. The remainder can be created at some other time prior to running SSX. Table 1 below summarizes the input data variables and the associated format.

\* (A) format is alphanumeric string variable

TABLE 1

## BASIC INFORMATION FILE (PARTIAL)

Data Set No.	Variables	Line Format
1	TITLE	(A)
2	TF, TA	6F10.0
3	XCG, YCG	6F10.0
4	(DRAFT(I), I=1,6)	6F10.0
5	(OM(I), I=1,12)	6F10.0
6	YMAX, ZMAX, WMAX, NWL	3F10.0, I15
7	NFWD	I5
8	(YFWD(I), XFWD(I), I=1,NFWD)	2F10.0
9	NAFT	I5
10	(YAFT(I), XAFT(I), I=1,NAFT)	2F10.0
.		
.		

A description of the variables contained in Table 1 is provided below:

- TITLE** - Any user-specified alphanumeric string up to 81 characters in length. This is displayed at the beginning of certain pages of output.
- XCG** - Distance aft of the forward perpendicular of the ship's center of gravity (ft).
- YCG** - Height above baseline of ship's center of gravity (ft)
- TF, TA** - Ships forward and after draft at FP and AP.
- DRAFT(I)** - An array of six drafts at which hydrodynamic coefficients are calculated. The specified drafts should cover a range beginning at approximately the height above the baseline of the top of the turn of the bilge and ending at the minimum hull depth. One of the drafts should be near the mean design draft for the displacement under consideration.
- OM(I)** - An array of twelve frequencies at which hydrodynamic coefficients are calculated.

- YMAX, ZMAX - Specifies the maximum desired vertical (YMAX) and horizontal separation between adjacent offset points for calculation of two-dimensional hydrodynamic coefficients. If both YMAX and ZMAX are positive values, interpolated offset points (straight line) will be added before computing coefficients using the method developed by W. Frank (1967).
- WMAX - A "deck" on the interior waterline has been added to the geometry of each station which is surface piercing to avoid "irregular" frequencies. The default is to use only one segment for this, but a positive WMAX will allow multiple segments each with a maximum length of WMAX.
- NWL - Specifies the number of interior waterline segments to be used to avoid "irregular" frequencies. The default is to use one segment, and this is selected if NWL is zero. A negative value (not recommended) will suppress the modification to Frank's procedure which eliminates irregular frequencies.
- NFWD - Number of forward profile points. This is restricted to  $0 < NFWD < 25$ . These points are numbered by the control variable I in a counterclockwise direction when viewed from the starboard side.
- YFWD(I) - Height of point I of the forward profile measured forward of the first station.'
- XFWD(I) - Distance of point I of the forward profile measured forward of the first station. If NWFD=1, XFWD(1) is defined to be the forward most point of the submerged hull.
- NAFT - Number of after profile points. This is restricted to  $0 < NAFT < 25$ . These points are numbered by the control variable I in a clockwise direction when viewed from the starboard side.
- YAFT(I) - Height of point I of the after profile.
- XAFT(I) - Distance of point I of the after profile measured aft of the last (MSTA) station. If NAFT=1, XAFT(1) is defined to be the after most point of the submerged hull.

The offset file [OFF] contains the ship's offsets in the SHCP\* format. An actual SHCP data can be used for the [OFF] file. HYDREX2 will read only what it needs. Table 2 below summarizes the input data variables and associated formats.

TABLE 2

SHIP OFFSET FILE		
Data Set Number	Variables	Line Format
1	SHCP Card A <u>or</u> (blank)	(A)
2	SHCP Card B <u>or</u> (blank)	(A)
3	SHCP Card C <u>or</u> space	F10.3, (A)
4	SHCP Card D - STATN, Y1 Z1, JTTEST	F6.3, 2F7.0,I6

A description of the variables contained in Table 2 is provided below.

SHCP CARD A - This can be left blank, or if it is an actual SHCP data file, leave it intact.

SHCP CARD B - Blank or actual SHCP Card B

SHCP CARD C - This can be the actual SHCP Card C or simply one variable or SPACE, where SPACE is the station spacing. It is actually a multiplier of the x-values of the stations given in the next card set.

STATN - The real distance from the station to the F.P. is the product of STATN and SPACE. The STATN values must be the same for all offsets on the same station.

---

\* Ship Hull Characteristic File (U.S. Navy)

- Y1            - The half breadth of the offset point. The offsets for each station should be ordered from the bottom toward the uppermost parts of the station.
- Z1            - The height of the offset point.
- JTEST        - The "breakpoint" indicator 77777 is ignored. The last offset on each station is signified by JTEST = 88888. The last offset on the last station is signified by JTEST = 99999. JTEST values other than zero (or blank) 77777, 88888 or 99999 are illegal.

For HYDREX2, the maximum number of offset points per station is 25. However, for SSX, the maximum number of offset points is 12. It is recommended that as many offset point (up to 25) as possible are used for HYDREX2 to increase the accuracy of the close-fit calculations. However, prior to running SSX, the [OFF] file must be edited to delete extra offset points in order to reduce the total number per station down to 12. The number of stations must be limited to 25.

An example of the actual input and output of HYDREX2 will be provided in Section 5 with a sample case illustration.

#### 4.2 PROGRAM HYDREX3

HYDREX3 calculates coordinates of hull surface panel center, areas and normal vectors of panels, body source density influence matrix [E], a body panel pressure influence matrix [PP], and a forward velocity source density influence matrix [PX].

When HYDREX3 is run, the only required input is the following two file names:

<u>File Name</u>	<u>Format</u>
Panel Description File [PAN]	(A)
Matrix and Geometry File [MAT]	(A)

Table 3 summarizes the input variables and formats for the data for the panel description file [PAN].

TABLE 3

PANEL DESCRIPTION FILE		
Data Set	Variables	Format
1	NPT, NPAN	4I5
2	XPT(N), YPT(N), ZPT(N) N=1, NPT	3F10.0
3	KK(M,1), KK(M,2), KK(M3,) KK(M,4), M=1, NPAN	4I5

The variables and their use are further described below.

NPT - Number of nodal points used to specify coordinates of panel corners. Not to exceed 150.

NPAN - Number of quadrilateral or triangular panels. Not to exceed 120.

XPT(N)  
YPT(N)  
ZPT(N) - The coordinates of the nodal points used as corner points for the panels. The coordinate system used here has Z positive downwards, X positive forward and Y positive starboard. The origin is at midships at the mean design water line.

KK(M,1) - These are four integers which identify which nodal points are used to define the corners of the panels. The convention for the sequencing of the aft panel corners is to go around the panel clockwise when viewed from outside of the ship hull along the panel normal.

#### 4.3 PROGRAM SSX

Program SSX performs a time domain simulation of ship motions, calculating hull girder loads and distributed pressures (optional). A prerequisite of executing SSX is to have run HYDREX2 and HYDREX3 in order to perform some "preprocessing". SSX requires four data files.

- (1) Basic Information Data File [BIF]
- (2) Ship Offset Data File [OFF]
- (3) 2-D Hydrodynamic Coefficient Data File [COF]
- (4) 3-D Geometry/Matrix File [MAT]

The program initially asks for the names of these four files in the above order. It then reads the data. If the [MAT] file name is 'NONE', then no pressure computations will be performed, and data sets 21 and 22 in the [BIF] file are skipped. The first eight data groups in the [BIF] file were given in Table 1. The variable and format list for the remainder of the [BIF] file is given in Table 4.

TABLE 4

BASIC INFORMATION FILE (PARTIAL)		
Data Set	Variables	Format
9	DISPL	8F10.0
10	(RADII(I), I=1,6)	8F10.0
11	SPEED	8F10.0
12	(DAMPL(I), I=1,6)	8F10.0
13	(DAMPQ(I), I=1,6)	8F10.0
14	IXWAVE IXWAVE = 1 → Include Set 14A IXWAVE ≠ 1 → Include Set 14B	I2
14A-1	NWAVES	4F10.0
14A-2	WVAMP(N), WVFR(E)(N), WVDIR(N), WVPHA(N), N=1, NWAVES	4F10.0
14B-1	H13, PKFRE, HEAD	8F10.0
15	(POSIT(I), I=1,6)	8F10.0
16	(VELOC(I), I=1,6)	8F10.0
17	TSTART, TSTOP, TOUTPT, TSTEP	8F10.0
18A	(JOBFO(10), I=1,10)	10I1
18B	(JOBPO(10), I=1,10)	10I1
⋮		

TABLE 4 (Cont.)

BASIC INFORMATION FILE (PARTIAL)		
Data Set	Variables	Format
18C	JOBCO	I1
19	NWTSTA	I2
20	SEGWT(I), SEGMOX(I), YBAR(I) I=1, NWTSTA	3F10.0
21	TPSTART, TPSTOP, TPRAMP	8F10.0
22	BGX, SMX, BGY, SMY, TSCALE	8F10.0

The variables and their use are further described below.

- DISPL - Ship displacement (long tons). It is best to enter the displacement calculated in HYDREX2 for the design draft and printed in the hydrostatic section of the HYDREX2 printout.
- RADI(1) - Radius of gyration for roll,  $\rho_{xx}$ .
- RADI(2) - Radius of gyration for yaw,  $\rho_{yy}$ ,
- RADI(3) - Radius of gyration for pitch,  $\rho_{zz}$ .
- RADI(4) - Radius of gyration,  $\rho_{xy}$ . The products of inertia are computed as:  
$$I_{xy} = I_{yx} = \rho_{xy} \cdot |\rho_{xy}| \cdot m$$
where m is the mass of the ship
- RADI(5) - Radius of gyration,  $\rho_{xz}$
- RADI(6) - Radius of gyration,  $\rho_{yz}$
- SPEED - Intended speed of the ship (feet/sec)
- DAMPL(1) - Linear surge damping
- DAMPL(2) - Linear heave damping
- DAMPL(3) - Linear sway damping
- DAMPL(4) - Linear roll damping
- DAMPL(5) - Linear yaw damping
- DAMPL(6) - Linear pitch damping
- DAMPQ(1) - Quadratic surge damping
- DAMPQ(2) - Quadratic heave damping
- DAMPQ(3) - Quadratic sway damping
- DAMPQ(4) - Quadratic roll damping
- DAMPQ(5) - Quadratic yaw damping
- DAMPQ(6) - Quadratic pitch damping

IXWAVE - Flag to indicate how the user wants to specify the wave system. IXWAVE=1 means the user will specify the amplitude, frequency, direction and phase angle of NWAVE wave components. IXWAVE ≠ 1 means the user will specify the significant height and modal frequency to be used for a two-parameter (Bretschneider) unidirectional sea spectral formulation from which 10 wave components will be calculated with random phse angles.

NWAVES - Number of sinusoidal waves. This is restricted to  $0 < \text{NWAVES} < 20$ .

WVAMP(I) - Amplitude of wave component I (ft)

WVFRE(I) - Circular frequency of wave component I

WVPHA(I) - Phase angle in degrees at time equal zero of wave component

H13 - Significant wave height in feet to be used in two-parameter Bretschneider unidirectional sea spectral formulation

PKFRE - Modal frequency in cycles/sec for Bretschneider formulation

POSIT(1) - Initial X-coordinate of mass center

POSIT(2) - Initial Y-coordinate of mass center

POSIT(3) - Initial Z-coordinate of mass center

POSIT(4) - Initial roll angle in degrees

POSIT(5) - Initial yaw angle in degrees

POSIT(6) - Initial pitch angle in degrees

VELOC(1) - Initial speed (ft./sec.)

VELOC(2) - Initial heave velocity

VELOC(3) - Initial sway velocity

VELOC(4) - Initial roll rate

VELOC(5) - Initial yaw rate

VELOC(6) - Initial pitch rate

The position values are specified with respect to the wave coordinate system fixed on the earth. The velocities are with respect to the ship coordinate system. Positions are in feet: velocities in feet/sec.

TSTART - Time at which the actual simulation is to start. All forces are multiplied by a ramp function that increases linearly in time from a value of zero at  $t=0$  to one at TSTART. This ramp is used to avoid transients caused by arbitrary initial conditions.

TSTOP - Time at which the simulation is to end

TOUTPT - Interval at which the ship position and velocity are to be output.

TSTEP - Integration time step

JOBCO - Option for selection of different techniques used to select the sectional hydrodynamic coefficients. The sectional coefficients may be calculated for any combination of fixed or varying draft and frequency dependence, according to the following table:

<u>JOBCO</u>	<u>Frequency</u>	<u>Draft</u>
1	Fix	Fix
2	Float	Fix
3	Fix	Float
4	Float	Float

The selection of fixed draft means the mean still waterline draft is always used for coefficient selection. Fixed frequency means the encounter frequency associated with the peak of the sea spectrum (for irregular waves) or the frequency of encounter for a regular wave is always used.

Floating frequency means the computed "characteristic" frequencies of motion as the simulation progresses are used. Floating draft means the actual instantaneous mean sectional draft is used at each time step.

- JOBFO(10)
  - Option array for which terms to include in the calculation of hydrodynamic forces. In the present version only JOBFO(2) and JOBFO(3) are used. If JOBFO(2)=1 then forward speed terms are included. If JOBFO(3)=1 then flare force is included. If JOBFO(4)=1, pressures in the wave above still water are assumed to be hydrostatic.
- JOBPO(10)
  - Printout option array. Only JOBPO(1) is used in present version. A value of 1 for JOBPO(1) will cause the initially selected values for hydrodynamic coefficients to be printed.
- NWTSTA
  - Number of weight stations. In present version of SSX, NWTSTA must equal number of hydrodynamic stations or strips.
- SEGWT(I)
  - Weight of weight station I (long-tons)
- SEGMOX(I)
  - Sectional roll gyradius (ft)
- YBAR(I)
  - Distance from section c.g. and waterline, positive up.
- TPZERO
  - Time at which to begin 3-D hull pressure computations
- TPSTART
  - Time at which 3-D hull pressure evaluation actually begins. Between time TPZERO and TPSTART, the exciting normal accelerations are multiplied by a ramp function that increases linearly in time from a value of zero at  $t = TPZERO$  to a value of one at  $t = TPSTART$
- TPSTOP
  - Time at which 3-D hull pressure evaluation ends
- BGX
  - Maximum longitudinal length scale. Corresponds to  $L_x$  in eq. (72) of Volume I. Try 2.5  $p_{pp}$
- SMX
  - Minimum longitudinal length scale corresponds to  $l_x$  in eq. (73) of Volume I. Try station spacing of ship

- BGY - Maximum transverse length scale. Corresponds to  $L_y$  in eq. (72) of Volume I. Try 5R
- SMY - Minimum transverse length scale. Corresponds to  $l_y$  in eq. (73) in Volume I. Try 0.1R
- TSCALE - Maximum time scale. Trade off between accuracy and computational effort. Try 0.6 (TPSTOP-TPZERO)

An example of actual input and output is shown in the next section with a sample run.

## 5. SAMPLE CASE

This example is for the SL-7 containership. An example of the [BIF], [OFF] and [PAN] data files are given. The [BIF] file is in free format. An example of the output for HYDREX2, HYDREX3 and SSX is given.

The sample case shows the full load SL-7 containership at 25 knots in head seas in a one-foot regular wave of  $\omega = 0.34$ . The basic information file [BIF] is shown in Figure 5. The offset [OFF] file is provided as Figure 6 and the panel file [PAN] is given as Figure 7. An example of the output of HYDREX2 is shown in Figure 8. An example of output of HYDREX3 is given in Figure 9. An example of output of SSX is given in Figure 10. Pressure data output is shown in Figure 11.

SL7 CONTAINERSHIP  
32.8,32.8  
-478.05,42.3005  
5.,10.,20.,32.8,40.,50.  
0.,0.,60.,2  
9  
0.,0.  
1.5,9.6  
8.25,16.88  
18.0,7.04  
30.,0.  
42.,1.92  
56.,7.92  
72.,17.12  
81.75,23.44  
6  
0.,-71.12  
6.0,-67.68  
10.75,-19.44  
25.0,-19.44  
33.0,12.24  
64.83,17.92  
47760  
47.,219.,219.,0.,0.,0.  
16.89  
0.,0.,0.,0.,0.,0.  
0.,0.,0.,0.,0.,0.  
1  
1  
1.,2,180.,0.  
0.,9.4118,0.,0.,0.  
16.89,0.,0.,0.,0.,0.  
30.,100.,5.,5  
25  
094.5500,37.31,9.5145  
294.5500,37.31,9.5145  
296.2025,37.31,9.5145  
496.2025,37.31,9.5145  
1143.8223,37.31,9.5145  
1134.9353,37.31,9.5145  
1681.7071,37.31,9.5145  
2040.0422,37.31,9.5145  
2508.4206,37.31,9.5145  
2578.8111,37.31,9.5145  
3053.3377,37.31,9.5145  
3591.3250,37.31,9.5145  
3530.8231,37.31,9.5145  
3175.7759,37.31,9.5145  
3725.5737,37.31,9.5145  
3530.6277,37.31,9.5145  
2595.3904,37.31,9.5145  
3151.4265,37.31,9.5145  
2534.0626,37.31,9.5145  
1915.6687,37.31,9.5145  
1761.7387,37.31,9.5145  
715.4792,37.31,9.5145  
715.4792,37.31,9.5145  
747.0264,37.31,9.5145  
747.0264,37.31,9.5145  
0.,0.,0.,0.  
0.,0.,0.,0.

- Figure 5. Basic Information File  
[BIF] -

## SL7 CONTAINERSHIP

44. 0250, 0, 0, 0, 0, 0  
 00. 00000. 000000. 0000  
 00. 00004. 480101. 6404  
 00. 00007. 081508. 2021  
 00. 00003. 815316. 4042  
 00. 00000. 289026. 2467  
 00. 00001. 011639. 3701  
 00. 00004. 277852. 4934  
 00. 00008. 237765. 124788888  
 00. 50000. 000000. 0000  
 00. 50003. 324000. 8202  
 00. 50006. 358903. 2808  
 00. 50006. 301113. 1234  
 00. 50003. 324019. 6850  
 00. 50001. 300729. 5276  
 00. 50002. 861539. 3701  
 00. 50007. 717452. 4934  
 00. 50013. 353764. 993488888  
 01. 00000. 000000. 0000  
 01. 00005. 202701. 6404  
 01. 00007. 659604. 9213  
 01. 00008. 237708. 2021  
 01. 00007. 804111. 4829  
 01. 00005. 838616. 4042  
 01. 00003. 179522. 9659  
 01. 00005. 058239. 3701  
 01. 00018. 007364. 960688888  
 01. 50000. 000000. 0000  
 01. 50004. 191100. 8202  
 01. 50007. 399503. 2808  
 01. 50008. 671206. 5617  
 01. 50008. 815809. 8425  
 01. 50008. 093213. 1234  
 01. 50005. 347319. 6850  
 01. 50004. 133326. 2467  
 01. 50007. 601839. 3701  
 01. 50011. 908552. 4934  
 01. 50022. 545264. 895088888  
 02. 00000. 000000. 0000  
 02. 00004. 624700. 8202  
 02. 00008. 035303. 2808  
 02. 00009. 480506. 5617  
 02. 00009. 682909. 8425  
 02. 00008. 960313. 1234  
 02. 00006. 937019. 6850  
 02. 00006. 214426. 2467  
 02. 00008. 006432. 8084  
 02. 00014. 452145. 9318  
 02. 00023. 065559. 0551  
 02. 00027. 112164. 796688888  
 03. 00000. 000000. 0000  
 03. 00002. 890400. 0656  
 03. 00007. 226001. 6404  
 03. 00010. 058604. 9213  
 03. 00010. 752308. 2021  
 03. 00011. 330411. 4829  
 03. 00011. 128116. 4042  
 03. 00011. 330422. 9659  
 03. 00013. 151429. 5276  
 03. 00018. 094039. 3701  
 03. 00026. 302752. 4934  
 03. 00034. 974064. 632588888  
 04. 00000. 000000. 0000  
 04. 00004. 335600. 1312  
 04. 00008. 757901. 6404  
 04. 00011. 908504. 9213  
 04. 00013. 584908. 2021  
 04. 00014. 741111. 4829  
 04. 00016. 330816. 4042  
 04. 00018. 354122. 9659  
 04. 00021. 042229. 5276  
 04. 00025. 782539. 3701  
 04. 00033. 528852. 4934  
 04. 00041. 911064. 534188888  
 05. 00000. 0000  
 05. 00004. 335 Figure 6. Offset File [OFF]  
 05. 00010. 839- Partial Listing  
 05. 00015. 319  
 05. 00018. 151  
 05. 00020. 232911. 4829  
 05. 00023. 036616. 4042  
 05. 00026. 013722. 9659  
 05. 00028. 904129. 5276

17. 00000. 440002. 4034  
 198968. 897688888  
 00026. 2467  
 757826. 2467  
 190732. 8084  
 346245. 9318  
 20. 00032. 084854. 6260  
 20. 00032. 084868. 897699999

Figure 7. Panel Description File  
[PAN] Partial Listing

SL7 CONTAINERSHIP

ADDED MASS/DAMPING COEFFICIENTS PROGRAM HYDREX

## Station 12

Dist. from F.P. -396.23  
 DRAFT (fwd) 32.80  
 DRAFT (aft) 32.80

Area 3031.365  
 Roll Ctr abv WL 0.088

F eq.	----HEAVE----		----SWAY----		----ROLL----		--SWAY-ROLL---	
	A22	B22	A33	B33	A44	B44	A34	B34
0.00	99.0000	0.0000	2.2896	0.0000	949.04	0.00	34.4	0.0
0.10	11.6174	0.8778	1.9201	0.0002	547.86	0.03	20.1	0.0
0.20	7.2671	1.4760	2.0412	0.0072	561.35	1.07	21.3	0.1
0.30	5.1586	1.8017	2.2434	0.0544	581.59	7.57	23.3	0.6
0.40	3.9867	1.9286	2.4304	0.2150	593.28	27.55	24.8	2.4
0.50	3.3206	1.9089	2.3837	0.5407	571.59	62.45	23.5	5.8
0.60	2.9645	1.7834	1.9918	0.9268	515.09	94.63	18.7	9.4
0.70	2.8127	1.5879	1.4567	1.1956	456.55	106.05	13.0	11.3
0.90	2.8677	1.1182	0.6952	1.3047	401.19	83.61	6.3	10.4
1.30	3.3945	0.4073	0.2841	0.9812	408.22	29.37	4.9	5.4
1.60	3.6990	0.1707	0.2848	0.7194	423.20	11.92	6.0	2.9
2.20	7.4603	0.0000	0.7945	0.0000	748.80	0.00	15.4	0.0

## -----STATION OFFSETS-----

Height above Baseline	Half BREADth	Submerged Offsets	
		-Y-	-Z-
0.000	0.000	-32.800	0.000
0.591	26.303	-32.209	26.303
0.820	30.060	-31.980	30.060
1.640	33.962	-31.160	33.962
3.281	38.298	-29.519	38.298
4.921	40.610	-27.879	40.610
6.562	42.778	-26.238	42.778
8.202	44.310	-24.598	44.310
9.842	45.524	-22.958	45.524
11.483	46.478	-21.317	46.478
13.123	47.345	-19.677	47.345
16.404	48.703	-16.396	48.703
19.685	49.715	-13.115	49.715
26.247	50.929	-6.553	50.929
29.528	51.305	-3.272	51.305
		WATERLINE	51.593
32.808	51.594		
39.370	52.027		
52.493	52.605		
64.304	52.750		

Figure 8. Output of HYDREX2  
Partial Listing

	NX	NY	NZ	XP	YP	ZP	AREA
1	0. 0000	0. 0000	1. 0000	390. 0000	0. 5867	30. 0000	79. 2000
2	0. 0176	0. 5404	0. 8412	405. 0000	3. 2150	28. 5000	499. 6292
3	0. 0264	0. 7592	0. 6504	405. 0000	6. 8350	25. 5000	355. 6513
4	0. 0301	0. 9964	-0. 0797	405. 0000	7. 8800	21. 0000	541. 9710
5	0. 0394	0. 9341	-0. 3549	405. 0000	6. 5000	15. 0000	578. 1236
6	0. 0525	0. 9600	-0. 2752	405. 0000	4. 5000	9. 0000	562. 5251
7	0. 0698	0. 9974	-0. 0166	405. 0000	3. 6200	4. 8000	216. 5585
8	0. 0000	0. 0000	1. 0000	325. 0000	1. 3000	30. 0000	182. 0000
9	0. 0120	0. 4445	0. 8957	325. 0000	5. 6225	28. 5000	472. 4277
10	0. 0283	0. 8527	0. 5216	325. 0000	9. 5625	25. 5000	246. 2683
11	0. 0365	0. 9992	0. 0133	336. 6667	10. 0800	22. 0000	210. 1590
12	0. 0694	0. 9962	0. 0531	325. 0000	10. 7600	16. 5000	632. 4223
13	0. 1151	0. 9722	0. 2037	325. 0000	11. 8800	7. 8000	604. 7363
14	0. 0000	0. 0000	1. 0000	257. 5000	2. 1200	30. 0000	275. 6000
15	0. 0158	0. 3772	0. 9260	257. 5000	7. 9225	28. 5000	516. 9807
16	7510	0. 7405	0. 6701	257. 5000	12. 9625	25. 5000	263. 3413
17		0. 9135	0. 3928	257. 5000	16. 9000	18. 0000	853. 8872
18		0. 9205	0. 3594	257. 5000	21. 8225	6. 0000	847. 3912
19	0.	0138	0. 9999	180. 0000	4. 5400	29. 9375	817. 2777
20	0. 000	74	0. 9424	195. 0000	10. 5600	28. 9167	404. 9271
21	0. 0125		0. 9458	165. 0000	18. 8533	26. 9167	799. 3557
22	0. 0532	-	0. 7425	195. 0000	20. 1067	25. 0000	203. 6394
23	0. 0786	-0. 6-	7547	180. 0000	27. 4450	18. 0000	1312. 5892
24	0. 1172	-0. 9156		180. 0000	34. 0325	6. 0000	134. 2212
25	0. 1012	-0. 9948		67. 5000	9. 8800	29. 8125	2668. 0806
26	0. 0000	-0. 0189	0.	0000	27. 6267	28. 7000	1157. 2611
27	0. 0000	-0. 1640	0. 984	70	28. 8000	26. 9167	1200. 2803
28	-0. 0131	-0. 6156	0. 7880		40. 1600	25. 0000	329. 7435
29	0. 0138	-0. 2842	0. 9587	-	*1. 9650	18. 0000	1871. 9629
30	0. 0481	-0. 9936	0. 1027	-60. u	7450	6. 0000	1657. 5626
31	0. 0062	-1. 0000	0. 0000	-60. 000		29. 7500	2376. 4260
32	0. 0000	-0. 0189	0. 9998	-120. 0000		28. 2500	1457. 4741
33	-0. 0257	-0. 1065	0. 9940	-150. 0000	-1b.	0000	219. 3015
34	-0. 0281	-0. 1878	0. 9818	-150. 0000	-37. 70	70	475. 0337
35	-0. 0249	-0. 2841	0. 9585	-120. 0000	-45. 5600		1116. 7516
36	-0. 0814	-0. 9296	0. 3594	-150. 0000	-47. 8533		70. 0344
37	-0. 0474	-0. 9514	0. 3044	-150. 0000	-51. 0933	8. u	130
38	0. 0000	-0. 1361	0. 9907	-210. 0000	-14. 5600	28. 000	
39	-0. 1575	-0. 4456	0. 8813	-240. 0000	-26. 4267	22. 0000	
40	-0. 1307	-0. 9247	0. 3576	-210. 0000	-42. 5333	16. 0000	585.
41	-0. 1182	-0. 8364	0. 5353	-240. 0000	-42. 4000	8. 0000	645. 65
42	0. 0000	-0. 7894	0. 6139	-330. 0000	-4. 6667	24. 0000	1026. 1578
43	-0. 1077	-0. 4486	0. 8872	-300. 0000	-16. 5333	18. 0000	1805. 6287
44	-0. 1705	-0. 7102	0. 6830	-330. 0000	-25. 0467	8. 0000	760. 3083
45	0. 1558	0. 8949	-0. 4183	-352. 5000	-20. 3800	13. 8333	1936. 0449
46	0. 0130	-0. 7893	0. 6139	-382. 5000	-5. 1457	23. 8333	769. 6833
47	-0. 1703	-0. 9843	0. 0462	-405. 0000	-6. 0733	15. 0000	891. 4889
48	-0. 2034	-0. 7057	0. 6787	-382. 5000	-14. 0867	5. 1667	573. 8820
49	0. 3141	0. 9442	-0. 0988	-405. 0000	-9. 4200	11. 0000	929. 3218
50	-1. 0000	0. 0000	0. 0000	-427. 5000	-3. 2100	11. 0000	49. 7100
51	-0. 1932	-0. 6290	0. 7530	-435. 0000	-3. 2100	1. 1667	62. 5984

Figure 9. Output of HYDREX3.  
Partial Listing

=====  
SL7 CONTAINERSHIP

=====  
PROGRAM SSX (Version 1.0)

-----WAVE COMPONENTS-----

WAVE	AMPLITUDE	FREQUENCY	DIRECTION	PHASE
1	1.00	0.34	180.00	0.00

-----SECTIONAL WEIGHT PROPERTIES-----

SECTION	WEIGHT	Kxx	Centroid
1	94.550	37.31	9.51
2	294.550	37.31	9.51
3	296.203	37.31	9.51
4	496.203	37.31	9.51
5	1143.822	37.31	9.51
6	1134.935	37.31	9.51
7	1681.707	37.31	9.51
8	2040.042	37.31	9.51
9	2508.421	37.31	9.51
10	2578.811	37.31	9.51
11	3053.338	37.31	9.51
12	3591.325	37.31	9.51
13	3530.823	37.31	9.51
14	3175.776	37.31	9.51
15	3725.574	37.31	9.51
16	3530.628	37.31	9.51
17	2595.390	37.31	9.51
18	3151.427	37.31	9.51
19	2534.063	37.31	9.51
20	1915.669	37.31	9.51
21	1761.739	37.31	9.51
22	715.479	37.31	9.51
23	715.479	37.31	9.51
24	747.026	37.31	9.51
25	747.026	37.31	9.51

Figure 10. Part of Output of SSX  
Partial Listing

=====  
3L7 CONTAINERSHIP

PROGRAM SSX (Version 1.0)

-----Inertial Characteristics-----

WEIGHT	47760.00	L. TONS	K <sub>xx</sub>	47.000	ft
XCG	-478.050	ft	K <sub>yy</sub>	219.000	ft
YCG	42.300	ft	K <sub>zz</sub>	219.000	ft
ZCG	0.000	ft	K <sub>xy</sub>	0.000	ft
			K <sub>xz</sub>	0.000	ft
			K <sub>yz</sub>	0.000	ft

-----DAMPING COEFFICIENTS-----  
(user specified)

MOTION	LINEAR	QUADRATIC
SURGE	0.0000E+00	0.0000E+00
HEAVE	0.0000E+00	0.0000E+00
SWAY	0.0000E+00	0.0000E+00
ROLL	0.0000E+00	0.0000E+00
YAW	0.0000E+00	0.0000E+00
PITCH	0.0000E+00	0.0000E+00

-----OPS DATA-----

SPEED 42.23

-----Initial Conditions-----

-----POSITION-----

X(CG)	0.000	ft
Y(CG)	9.412	ft
Z(CG)	0.000	ft
ROLL	0.000	deg
YAW	0.000	deg
PITCH	0.000	deg

-----VELOCITY-----

SPEED	42.230	ft/sec
HEAVE	0.000	ft/sec
SWAY	0.000	ft/sec
ROLL	0.000	deg/sec
YAW	0.000	deg/sec
PITCH	0.000	deg/sec

-----Run Parameters-----

SIMULATION PARAMETERS

TIME(START)	30.00
TIME(END)	100.00
OUTPUT DT	0.50
INTEG. DT	0.50

JOB OPTIONS

-----MISCELLANEOUS VALUES-----

RHO	0.000889
G	32.169998
JOBCO	1
JOBFO	1 1 0

Figure 10. Part of Output of SSX  
Partial Listing

TIME	WAVE	POSITION OF CENTER OF GRAVITY		
		X	Y	Z
0. 0000	1. 0000	0. 0000	0. 0000	0. 0000
0. 5000	0. 9702	21. 1150	0. 0002	0. 0000
1. 0000	0. 8825	42. 2301	0. 0016	0. 0000
1. 5000	0. 7422	63. 3456	0. 0048	0. 0000
2. 0000	0. 5576	84. 4618	0. 0101	0. 0000
2. 5000	0. 3397	105. 5792	0. 0169	0. 0000
3. 0000	0. 1016	126. 6983	0. 0238	0. 0000
3. 5000	-0. 1426	147. 8197	0. 0285	0. 0000
4. 0000	-0. 3783	168. 9435	0. 0284	0. 0000
4. 5000	-0. 5914	190. 0700	0. 0202	0. 0000
5. 0000	-0. 7693	211. 1992	0. 0009	0. 0000
5. 5000	-0. 9012	232. 3307	-0. 0322	0. 0000
6. 0000	-0. 9794	253. 4639	-0. 0808	0. 0000
6. 5000	-0. 9991	274. 5980	-0. 1451	0. 0000
7. 0000	-0. 9592	295. 7319	-0. 2235	0. 0000
7. 5000	-0. 8621	316. 8644	-0. 3120	0. 0000
8. 0000	-0. 7135	337. 9943	-0. 4046	0. 0000
8. 5000	-0. 5224	359. 1200	-0. 4931	0. 0000
9. 0000	-0. 3001	380. 2405	-0. 5676	0. 0000
88. 0000	0. 6254	3715. 1992	0. 9302	0. 0000
88. 5000	0. 7957	3736. 2339	1. 0866	0. 0000
89. 0000	0. 9187	3757. 2551	1. 1782	0. 0000
89. 5000	0. 9870	3778. 2671	1. 1995	0. 0000
90. 0000	0. 9966	3799. 2751	1. 1492	0. 0000
90. 5000	0. 9469	3820. 2847	1. 0303	0. 0000
91. 0000	0. 8409	3841. 3008	0. 8500	0. 0000
91. 5000	0. 6849	3862. 3284	0. 6189	0. 0000
92. 0000	0. 4881	3883. 3718	0. 3509	0. 0000
92. 5000	0. 2621	3904. 4341	0. 0621	0. 0000
93. 0000	0. 0205	3925. 5173	-0. 2304	0. 0000
93. 5000	-0. 2224	3946. 6223	-0. 5090	0. 0000
94. 0000	-0. 4521	3967. 7488	-0. 7573	0. 0000
94. 5000	-0. 6549	3988. 8945	-0. 9603	0. 0000
95. 0000	-0. 8187	4010. 0569	-1. 1060	0. 0000
95. 5000	-0. 9335	4031. 2317	-1. 1858	0. 0000
96. 0000	-0. 9926	4052. 4143	-1. 1949	0. 0000
96. 5000	-0. 9924	4073. 5996	-1. 1329	0. 0000
97. 0000	-0. 9328	4094. 7822	-1. 0034	0. 0000
97. 5000	-0. 8176	4115. 9570	-0. 8141	0. 0000
98. 0000	-0. 6535	4137. 1196	-0. 5763	0. 0000
98. 5000	-0. 4504	4158. 2656	-0. 3041	0. 0000
99. 0000	-0. 2205	4179. 3926	-0. 0138	0. 0000
99. 5000	0. 0225	4200. 4980	0. 2774	0. 0000
100. 0000	0. 2640	4221. 5815	0. 5521	0. 0000
RMS	0. 7112	304. 5160	0. 8489	0. 0000
MEAN	0. 0000	-0. 0134	3704. 3413	-0. 0220
MAX	0. 0000	1. 0000	4221. 5815	1. 2009
MIN	0. 0000	-0. 9991	0. 0000	-1. 1991

- Figure 10. Left side of 132 character width printout of SSX (partial)

ROTATIONS IN DEGREES				
ROLL	YAW	PITCH	MIDS. VERT	SPEED
0. 0000	0. 0000	0. 0000	0. 00000E+00	42. 2300
0. 0000	0. 0000	0. 0000	-0. 57850E+06	42. 2301
0. 0000	0. 0000	-0. 0002	-0. 60541E+06	42. 2305
0. 0000	0. 0000	-0. 0008	-0. 63125E+06	42. 2315
0. 0000	0. 0000	-0. 0021	-0. 65431E+06	42. 2335
0. 0000	0. 0000	-0. 0047	-0. 67303E+06	42. 2364
0. 0000	0. 0000	-0. 0088	-0. 68603E+06	42. 2403
0. 0000	0. 0000	-0. 0148	-0. 69229E+06	42. 2451
0. 0000	0. 0000	-0. 0227	-0. 69116E+06	42. 2503
0. 0000	0. 0000	-0. 0323	-0. 68247E+06	42. 2557
0. 0000	0. 0000	-0. 0433	-0. 66658E+06	42. 2608
0. 0000	0. 0000	-0. 0548	-0. 64439E+06	42. 2649
0. 0000	0. 0000	-0. 0656	-0. 61736E+06	42. 2676
0. 0000	0. 0000	-0. 0745	-0. 58740E+06	42. 2684
0. 0000	0. 0000	-0. 0800	-0. 55682E+06	42. 2669
0. 0000	0. 0000	-0. 0806	-0. 52814E+06	42. 2628
0. 0000	0. 0000	-0. 0751	-0. 50389E+06	42. 2560
0. 0000	0. 0000	-0. 0626	-0. 48633E+06	42. 2446
0. 0000	0. 0000	-0. 0427	-0. 47728E+06	42. 2117
0. 0000	0. 0000	0. 2165	-0. 62122E+06	42. 0858
0. 0000	0. 0000	0. 1917	-0. 62237E+06	42. 0545
0. 0000	0. 0000	0. 1554	-0. 62240E+06	42. 0315
0. 0000	0. 0000	0. 1099	-0. 62129E+06	42. 0183
0. 0000	0. 0000	0. 0577	-0. 61914E+06	42. 0157
0. 0000	0. 0000	0. 0021	-0. 61605E+06	42. 0238
0. 0000	0. 0000	-0. 0537	-0. 61218E+06	42. 0422
0. 0000	0. 0000	-0. 1062	-0. 60782E+06	42. 0697
0. 0000	0. 0000	-0. 1523	-0. 60310E+06	42. 1047
0. 0000	0. 0000	-0. 1893	-0. 59842E+06	42. 1451
0. 0000	0. 0000	-0. 2149	-0. 59400E+06	42. 1883
0. 0000	0. 0000	-0. 2275	-0. 59013E+06	42. 2318
0. 0000	0. 0000	-0. 2265	-0. 58704E+06	42. 2730
0. 0000	0. 0000	-0. 2118	-0. 58496E+06	42. 3092
0. 0000	0. 0000	-0. 1846	-0. 58401E+06	42. 3385
0. 0000	0. 0000	-0. 1463	-0. 58419E+06	42. 3591
0. 0000	0. 0000	-0. 0993	-0. 58556E+06	42. 3697
0. 0000	0. 0000	-0. 0465	-0. 58798E+06	42. 3697
0. 0000	0. 0000	0. 0091	-0. 59137E+06	42. 3593
0. 0000	0. 0000	0. 0641	-0. 59538E+06	42. 3399
0. 0000	0. 0000	0. 1154	-0. 59986E+06	42. 3098
0. 0000	0. 0000	0. 1598	-0. 60459E+06	42. 2737
0. 0000	0. 0000	0. 1948	-0. 60915E+06	42. 2327
0. 0000	0. 0000	0. 2183	-0. 61340E+06	42. 1891
0. 0000	0. 0000	0. 2289	-0. 61708E+06	42. 1456
0. 0000	0. 0000	0. 1599	0. 13537E+05	0. 1269
0. 0000	0. 0000	-0. 0053	-0. 60289E+06	42. 1984
0. 0000	0. 0000	0. 2289	0. 00000E+00	42. 3768
0. 0000	0. 0000	-0. 2282	-0. 62252E+06	0. 0000

Figure 10. Right side of 132 character  
- width printout of SSX (partial)

## PR SURES

0. 28415968	0. 24316381	0. 23651379	0. 22607508	0. 2106125 <sup>E</sup>
0. 19246852	0. 17776074	1. 14601755	1. 16095650	1. 15
1. 05791485	1. 29189086	1. 40567327	2. 06866050	
2. 15990114	2. 33326197	2. 64962888	3. 077	
3. 24160838	2. 96588731	3. 32186317		
4. 04283953	3. 78925920	3. 97777		
4. 74622965	4. 53059387			
5. 02411795	5. 23495 <sup>E</sup>			
5. 02339220	-			
5. 838945 <sup>E</sup>				

## ----TOTAL PRESSURES----

-1. 46834481	-0. 83654284	-0. 78719705	-1. 71809840	0. 00665942
0. 23063746	1. 18806934	-0. 45587230	-0. 17283618	0. 357 <sup>E</sup>
17. 64413261	2. 48809695	1. 18732226	0. 37171781	
1. 17200983	1. 83491194	2. 47403312	0. 99945 <sup>E</sup>	
1. 39725995	1. 88052142	2. 80034971	-	
1. 43834829	1. 74238777	2. 9354397 <sup>E</sup>		
2. 78261328	2. 71100593	3. 51		
56. 71600723	3. 11889052			
8. 52794075	7. 50151			

## B DY INDUCED PRESSURES

-1. 85250449	-1. 07970667	-1. 02371085	-1. 94417346	-0. 20395313
0. 03816893	1. 01030862	-1. 60188985	-1. 33379269	-0. 83561438
16. 58621788	1. 19620597	-0. 21835098	-1. 69694269	-1. 50451446
-0. 98789138	-0. 49835002	-0. 17559581	-2. 02371120	-1. 95836079
-1. 84434843	-1. 08536589	-0. 52151340	-0. 05880385	-2. 24148512
-2. 60449123	-2. 04687142	-1. 03688288	0. 02363856	1. 00506485
-1. 96361649	-1. 81958807	-0. 79081982	-1. 89128637	2. 57368040
51. 69189072	-2. 11605954	-1. 65408003	-1. 66934085	-1. 67518842
3. 50454855	1. 93148851	-1. 43030024	-0. 60449553	1. 84978557
0. 40260637	-0. 62282950	-0. 58973241	-0. 03671409	2. 83566427
-0. 41253781	0. 83666974	-0. 10891942	0. 55786502	0. 00000000
0. 03906842	-2. 58687186	-1. 62076259	-0. 77843022	7. 79187298
-0. 35989502	-0. 11269927	-0. 31951666	-1. 83989894	-1. 40328050
-0. 73166758	11. 49159718	-0. 16707416	-0. 29368657	-1. 92022955
-1. 52942920	-1. 04738855	-0. 60960990	-0. 22613873	-2. 24740911
-1. 75089848	-1. 78046894	-0. 91861057	-0. 41995618	0. 12429215
-2. 62914538	-2. 34276557	-1. 72142696	-1. 22348630	1. 35021770
30. 93821144	-2. 01162410	-1. 54072320	-0. 79989606	-1. 55071521
10. 87392330	0. 00000000	-2. 08891344	-1. 69489515	-1. 51071918
-1. 30158806	2. 16383004	1. 18314898	-1. 51980424	-0. 68915701
1. 78912711	0. 56204945	-0. 96726221	-0. 71865982	-0. 38488629
0. 34184885	-0. 67282838	-0. 67956263	-0. 36257684	0. 79844165
0. 00000000	-0. 03861484			

- Figure 11. Pressure output of SSX  
(partial listing for one time step) -

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APPENDIX A

Program Listings

HYDREX2

HYDREX3

SSX

PROGRAM SSX

```
C CHARACTER*25 OFFIL, BIFIL, COFIL, MATFIL
CHARACTER*30 TITLE
COMMON/HEAD/TITLE
COMMON/IOFILE/ OFFIL, BIFIL, COFIL, MATFIL
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF, MAT
INTEGER OUTPUT, BIF, OFF, COF
COMMON /COEFF4 / COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON/OPTION/JOBCO, JOBFO(10), JOBPO(10)
COMMON/JOBP/JOBP
COMMON /JOBB/ IJOB, IFORCE, IAIXIS, IWANT
COMMON /           NWAVES, WVSUM,
1           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2           WN(20), WNX(20), WNZ(20),
3           CSK(20), CCK(20), CXK(20),
4           CYK(20), CZK(20), XW(20)
COMMON /           MSTA, NPROF, NFWD, NAFT, LPTS(25),
1           XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2           XPROF(51), YPROF(51)
COMMON /DAMP  / DAMPL(6), DAMPG(6)
COMMON /LHS   / Y(13)
COMMON /MASS  / RHO, G, GAMMA
COMMON /MASS  / DISPL, SMASS, XCG, YCG, ZCG,
1           AMX, AMY, AMZ, RADII(6)
COMMON /MASS  / PMI(3,3)
COMMON /RESIST/ SPEED
COMMON /TIME  / TIME, RAMP
COMMON /TIME  / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE
COMMON/DRFT1/ DRAFT1(6)
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON /STATS / NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1
DATA TO /0. 0/
DATA NEQS /12/
LOGICAL WL, ADJUST, INTERACT
DATA RHO /0. 00088861607142/
DATA ERRO/1.0E-37/
DATA INPUT/5/, OUTPUT/6/, BIF/1/, OFF/2/, COF/9/
DATA MAT/3/
```

```
C-----
C *** 1.0 Get DATA file names and assign/open files
C
TYPE 902
ACCEPT 901, BIFIL
TYPE 903
ACCEPT 901, OFFIL
TYPE 904
ACCEPT 901, COFIL
TYPE 905
ACCEPT 901, MATFIL
C
OPEN(UNIT=BIF, STATUS='OLD', FILE=BIFIL)
OPEN(UNIT=OFF, STATUS='OLD', FILE=OFFIL)
OPEN(UNIT=COF, STATUS='OLD', FORM='UNFORMATTED', FILE=COFIL)
IF(MATFIL.NE.'NONE') OPEN(UNIT=MAT, STATUS='OLD', FORM='UNFOR
1 MATTED', FILE=MATFIL)
C
*** 2.0 Read in data from [BIF], [OFF] and [COF] files
CALL READIN
C
*** 3.0 Perform preparatory computations
CALL PREPARE
C
CALL COFFEE
CALL FOLIO1
IF(JOBPO(1).EQ. 1) CALL OUTCOF
```

```

C *** 5.0 Simulation
C
      WRITE (OUTPUT,130)
      TSTEP=-ABS(TSTEP)
      TIME=TO
      TTO=TO
      TT1=TO
  110 CALL FOLIO2                      !Show time zero condition
      TNEXT=TIME+TOUTPT
C *** Fourth-order Runge-Kutta integration
      CALL RKF (TIME,Y,TNEXT,ERR,NEQS,TSTEP)
C *** Get hull girder loads
      CALL HULL
C *** Get panel pressures
      TP=TIME-TPSTART
      IF(TP.GE.0..AND.TP.LE.TPSTART) CALL PRESSURE(TP)
C
      TIME=TNEXT
      IF (TIME.LT.TSTOP) GO TO 110
  120 CALL FOLIO2
      CALL FINI
      STOP
C
  130 FORMAT (1H1,27X,29HPOSITION OF CENTER OF GRAVITY,
$         9X,20HROTATIONS IN DEGREES,27X,19HHORIZONTAL VELOCITY/
$         4X,4HTIME,BX,4HWAVE,BX,1HX,11X,1HY,11X,1HZ,13X,
$         4HROLL,9X,3HYAW,7X,5HPITCH,6X,6HRUDDER,
$         7X,5HSPEED,SX,9HSWAY RATE/)

C
  901 FORMAT(A)
  902 FORMAT(' Name of Basic INPUT File [BIF] ? > ')
  903 FORMAT(' Name of Offset File [OFF] ? > ')
  904 FORMAT(' Name of Coefficient File [COF] ? > ')
  905 FORMAT(' Name of 3-D Matrix File [MAT] ? > ')
C
      END

```

SUBROUTINE READIN

C COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF, MAT  
INTEGER OUTPUT, BIF, OFF, COF  
INTEGER ECHO  
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)  
COMMON/DRFT1/DRAFT1(6)  
COMMON/IOFILE/ OFIL, BIFIL, COFIL, MATFIL  
COMMON/HEAD/TITLE  
CHARACTER\*30 TITLE  
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)  
COMMON/OPTION/JOBCO, JOBFO(10), JOBPO(10)  
COMMON / / NWAVES, WVSUM,  
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),  
2 WN(20), WNX(20), WNZ(20),  
3 CSK(20), CCK(20), CXK(20),  
4 CYK(20), CZK(20), XW(20)  
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),  
1 XOFF(25), YOFF(25, 25), ZOFF(25, 25),  
2 XPROF(51), YPROF(51),  
COMMON /DAMP / DAMPL(6), DAMPQ(6)  
COMMON /LHS / Y(13)  
COMMON /MASS / RHO, G, GAMMA  
COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,  
1 AMX, AMY, AMZ, RADII(6)  
COMMON /MASS / PMI(3,3)  
COMMON /RESIST/ SPEED  
COMMON /TIME / TIME, RAMP  
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR  
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMOM(26),  
\* STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA  
REAL XAFT(25), YAFT(25), XFWD(25), YFWD(25)  
EQUIVALENCE (XFWD(1), XPROF(1)), (YFWD(1), YPROF(1)),  
\$ (XAFT(1), XPROF(26)), (YAFT(1), YPROF(26))  
COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE  
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREAP(120),  
\* ST(120), ACN(120), ACNW(120), AN(120, 3), E(120), P(120, 6),  
\* PRFS(120), STOLD(120), PX(120, 6)  
COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD  
COMMON/SOURCE/ EE(120, 120)  
REAL POSIT(6), VELOC(6)  
COMMON/DISPLAY/TARE(6)  
EQUIVALENCE (POSIT(1), Y(1)), (VELOC(1), Y(7))  
DATA MAXSTA/25/  
DATA MAXPTS/25/  
DATA MAXFWD/25/  
DATA MAXAFT/25/  
DATA MAXWVS/20/  
DATA TPSTOP/0./  
DATA ERRMIN/1.0E-10/  
CHARACTER\*81 CARDID  
DATA DEGREE/0.01745 32925 19943/  
DATA G /32.17/  
DATA NWL/1/  
DATA ECHO/4/  
C \*\*\* OPEN DATA FILE ECHO PRINTOUT FILE  
OPEN(UNIT=ECHO, TYPE='NEW', NAME='ECHO.DAT')  
C  
C \*\*\* WRITE(ECHO, 197)  
C \*\*\* TITLE  
READ(BIF, 199) TITLE  
WRITE(ECHO, 196) TITLE  
C \*\*\* DRAFT (fwd), DRAFT (aft), long. loc's of DRAFT marks  
READ(BIF, 200) TF, TA, XFFERP, XAPERP  
WRITE(ECHO, 200) TF, TA, XFFERP, XAPERP  
C \*\*\* Center of Gravity (XCG aft of FP, YCG above BL)  
READ(BIF, 200) XCG, YCG, ZCG  
WRITE(ECHO, 200) XCG, YCG, ZCG  
C \*\*\* Six DRAFTs at which hydro. coeffs are computed  
READ(BIF, 200) (DRAFT1(I), I=1, 6)  
WRITE(ECHO, 200) (DRAFT1(I), I=1, 6)  
C \*\*\* Minimum segment lengths for Frank Close Fit  
READ(BIF, 201) YMAX, ZMAX, WMAX, NWL  
WRITE(ECHO, 201) YMAX, ZMAX, WMAX, NWL  
ADJUST=ZMAX. GT. 0.0 AND. YMAX. GT. 0.0

```

C *** Number of forward profile points
READ(BIF, 190) NFWD
WRITE(ECHO, 190) NFWD
IF (NFWD.GT.25) CALL ERROR(15, IDUM, RDUM)
C *** Coordinates of forward profile points
IF (NFWD.GT.0) READ(BIF, 430) (YFWD(I), XFWD(I), I=1, NFWD)
WRITE(ECHO, 430) (YFWD(I), XFWD(I), I=1, NFWD)
C *** Number of aft profile points
READ(BIF, 190) NAFT
WRITE(ECHO, 190) NAFT
IF (NAFT.GT.25) CALL ERROR(16, IDUM, RDUM)
C *** Coordinates of aft profile points
IF (NAFT.GT.0) READ(BIF, 430) (YAFT(I), XAFT(I), I=1, NAFT)
WRITE(ECHO, 430) (YAFT(I), XAFT(I), I=1, NAFT)
C *** Displacement
READ(BIF, 202) DISPL
WRITE(ECHO, 200) DISPL
C *** Radii of gyration
READ(BIF, 202) RADII
WRITE(ECHO, 200) RADII
C *** Ship speed
READ(BIF, 202) SPEED
WRITE(ECHO, 200) SPEED
C *** Linear Damping Constants
READ(BIF, 202) DAMPL
WRITE(ECHO, 200) DAMPL
C *** Quadratic Damping Constants
READ(BIF, 202) DAMPQ
WRITE(ECHO, 200) DAMPQ
C *** Number of wave components
WRITE(ECHO, 203) NWAVES
READ(BIF, 203) NWAVES
C *** Wave component specifications
DO 140 J=1, NWAVES
READ(BIF, 202) WVAMP(J), WVFRE(J), WVDIR(J), WVPHA(J)
WRITE(ECHO, 200) WVAMP(J), WVFRE(J), WVDIR(J), WVPHA(J)
140 CONTINUE
C *** Initial position
READ(BIF, 202) POSIT
WRITE(ECHO, 200) POSIT
C *** Initial velocities
READ(BIF, 202) VELOC
WRITE(ECHO, 200) VELOC
C *** Simulation specification
READ(BIF, 202) TSTART, TSTOP, TOUTPT, TSTEP
WRITE(ECHO, 200) TSTART, TSTOP, TOUTPT, TSTEP
C *** Number of weight stations
READ(BIF, 203) NWTSTA
WRITE(ECHO, 203) NWTSTA
C *** Segment weight, rotational gyradii , centroid
DO 141 J=1, NWTSTA
READ(BIF, 202) SEGWT(J), SEGMX(J), YBAR(J)
WRITE(ECHO, 200) SEGWT(J), SEGMX(J), YBAR(J)
141 CONTINUE
C
IF(MATFIL.EQ.'NONE') GO TO 1000
READ(BIF, 202) TPSTART, TPSTOP, TPRAMP
WRITE(ECHO, 200) TPSTART, TPSTOP, TPRAMP
READ(BIF, 202) BGX, SMX, BGY, SMY, TSCALE
WRITE(ECHO, 200) BGX, SMX, BGY, SMY, TSCALE
C
C-----  

C
C Section 2.0 - READ OFFSET file
C The offset file can be an actual SHCP DATA File
1000 CONTINUE
WRITE(ECHO, 198)
C
C *** CARD TYPE A
READ(UFF, 410) CARDID
WRITE(ECHO, 410) CARDID
C *** CARD TYPE B
READ(OFF, 410)
C *** CARD TYPE C
READ(OFF, 412) SPACE, ZSCAL, YSCAL, SHIPL, NAPN, KINDO
WRITE(ECHO, 412) SPACE, ZSCAL, YSCAL, SHIPL, NAPN, KINDO
IF (SPACE.EQ.0.0) SPACE=1.0
ZSCAL=1.0
YSCAL=1.0
MSTA=0
NFWD=0
NAFT=0

```

```

C      SUBROUTINE AFSR
      INTI IALIZES FREE SURFACE
      COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
      * ACN(120),ACNW(120),AN(120,3),E(-20),P(120,6),PRFS(120),
      * STOLD(120),PX(120,6)
      * COMMON/FS/AKZ(100,100),SS(100,100),CC(100,100),
      * DDX(100),DKY(100),AKX(100),AKY(100)
      COMMON/FS1/A(100,100),B(100,100),AS(100,100),BS(100,100)
      COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFWD
      COMMON/PREXIN/TPSTART,TPSTOP,TPRAMP,BGX,SMX,BGY,SMY,TSCALE
      COMPLEX A,B,AS,BS,EYE
      DKTT=1.0/(GEE*TSCALE*TSCALE)
      NBX=0.5/(BGX*DKTT)
      NBY=0.5/(BGY*DKTT)
      AMX=1.0/SMX
      AMY=1.0/SMY
      N=0
      M=0
      AOLD=0.0
      1 IF(N.GE.NBX) GO TO 2
      N=N+1
      AKX(N)=N*N*DKTT
      AOLD=AKX(N)
      IF(AOLD.GE.AMX) NBX=N
      GO TO 1
      2 N=N+1
      AKX(N)=AOLD+1.0/BGX
      AOLD=AKX(N)
      IF(AOLD.LE.AMX) GO TO 2
      NKX=N
      AKX(NKX+1)=AOLD+1.0/BGX
      AOLD=0.00
      11 IF(M.GE.NBY) GO TO 22
      M=M+1
      AKY(M)=M*M*DKTT
      AOLD=AKY(M)
      IF(AOLD.GE.AMY) NBY=M
      GO TO 11
      22 M=M+1
      AKY(M)=AOLD+1.0/BGY
      AOLD=AKY(M)
      IF(AOLD.LE.AMY) GO TO 22
      NKY=M
      AKY(M+1)=AKY(M)+1.0/BGY
      AFF=0.000
      DO 17 N=1,NKX
      AF=(AKX(N+1)+AKX(N))*0.50
      DKX(N)=AF-AFF
      AFF=AF
      BFF=0.00
      DO 18 N=1,NKY
      BF=(AKY(N+1)+AKY(N))*0.50
      DKY(N)=BF-BFF
      BFF=BF
      DO 100 N=1,NKX
      DO 100 M=1,NKY
      A(N,M)=(0.0,0.0)
      B(N,M)=(0.0,0.0)
      AS(N,M)=(0.0,0.0)
      BS(N,M)=(0.0,0.0)
      AKZ(N,M)=SQRT(AKX(N)**2+AKY(M)**2)
      SIG=SQRT(GEE*AKZ(N,M))
      SS(N,M)=SIN(SIG*DT)
      CC(N,M)=COS(SIG*DT)
      100 CONTINUE
      RETURN
      END

```

C SUBROUTINE PRESSURE(TP)

```
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF, MAT
INTEGER OUTPUT, BIF, OFF, COF
INTEGER ECHO
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON/DRFT1/DRAFT1(6)
COMMON/IOFILE/ OFFIL, BIFIL, COFIL, MATFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON /          / NWAVES, WVSUM,
1           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2           WN(20), WNX(20), WNZ(20),
3           CSK(20), CCK(20), CXK(20),
4           CYK(20), CZK(20), XW(20)
COMMON /          / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1           XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2           XPROF(51), YPROF(51)
COMMON /DAMP  / DAMPL(6), DAMPG(6)
COMMON /LHS   / Y(13)
COMMON /MASS  / RHO, G, GAMMA
COMMON /MASS  / DISPL, SMASS, XCG, YCG, ZCG,
1           AMX, AMY, AMZ, RADII(6)
COMMON /MASS  / PMI(3, 3)
COMMON /RESIST/ SPEED
COMMON /TIME  / TIME, RAMP
COMMON /TIME  / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMOM(26),
*      STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
REAL XAFT(25), YAFT(25), XFWD(25), YFWD(25)
EQUIVALENCE (XFWD(1), XPROF(1)), (YFWD(1), YPROF(1)),
$      (XAFT(1), XPROF(26)), (YAFT(1), YPROF(26))
COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120),
*      ST(120), ACN(120), ACNW(120), AN(120, 3), E(120), P(120, 6),
*      PRFS(120), STOLD(120), PX(120, 6)
COMMON/FS/AKZ(100, 100), SS(100, 100), CC(100, 100),
*      DKX(100), DKY(100), AKX(100), AKY(100)
COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150),
*      WRFR(150), KK(150, 4)
COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
REAL POSIT(6), VELOC(6)
COMMON/SOURCE/EE(120, 120), BPRES(120), PT(6)
COMMON/DISPLAY/TARE(6)
```

C-----  
C  
C

TIM=TP  
UFWD=YY(7)

C \*\*\* Get free surface induce component of normal acceleration  
at panel centers ACNW(J) and pressure force array PF.

C CALL ACPTR

C \*\*\* Get exciting normal acceleration at panel centers

C CALL XNA(AXMT, AYMT, AZMT, ARLMT, APMT, AYWMT)

C \*\*\* Compute panel source strengths

C CALL ZBLACN(AXMT, AYMT, AZMT, ARLMT, APMT, AYWMT)

C \*\*\* Compute body induced forces and pressures

C CALL POTB

C \*\*\* Advance free surface for single time step

C CALL CFSR

C \*\*\* Forces and moments

C CALL PRFR(PT)

C RETURN

END

```

C SUBROUTINE ACPTR
C Computes wave induced accelerations and pressures at
C panel centers
* COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
* ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
* STOLD(120), PX(120,6)
* COMMON/FS/AKZ(100,100), SS(100,100), CC(100,100),
* DDX(100), DKY(100), AKX(100), AKY(100)
* COMMON/FS1/A(100,100), B(100,100), AS(100,100), BS(100,100)
* COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
* COMPLEX EYE, SC, BX, CX, BY, CY, BYCON, SCON, SK, SKON,
* B1, B2, C1, C2
* COMPLEX A, B, AS, BS
* DIMENSION BX(100), CX(100), PF(6), DX(100)
* DO 1500 J=1, NPAN
* AX=AN(J,1)
* AY=AN(J,2)
* AZ=AN(J,3)
* X=XPAN(J)
* Y=YPAN(J)
* Z=ZPAN(J)
* ACT=0.00
* PRT=0.00
* DVZDZ=0.00
* DO 16 N=1, NKX
* CCXX=AKX(N)*X
* S=SIN(CCXX)
* C=COS(CCXX)
* BX(N)=CMPLX(C,S)*DDX(N)
* DX(N)=-AKX(N)*AKX(N)*AX
* CX(N)=AKX(N)*AX*EYE
16   DO 163 M=1, NKY
* CCYY=AKY(M)*Y
* S=SIN(CCYY)
* C=COS(CCYY)
* BY=CMPLX(C,S)*DKY(M)
* BYCON=CONJG(BY)
* CY=AKY(M)*AY*EYE
* DO 163 N=1, NKX
* ARGZ=AKZ(N,M)*Z
* DEP=EXP(-ARGZ)
* B1=DEP*BY*BX(N)
* B2=DEP*BYCON*BX(N)
* CZ=AKZ(N,M)*AZ
* SC=B1*A(N,M)
* SCON=B2*AS(N,M)
* SK=B1*B(N,M)
* SKON=B2*BS(N,M)
* C1=CX(N)+CY-CZ
* C2=CX(N)-CY-CZ
* ACT=ACT-C1*SC-C2*SKON
* DVZ=DVZ+EYE*AKX(N)*(C1*SK+C2*SKON)/SQRT(AKZ(N,M))
* PRT=PRT+SC+SCON
* CONTINUE
163  C NORMAL ACCELERATION INDUCED BY FREE SURFACE
* DVZ=DVZ*UFWD*SQRT(GEE)
* ACNW(J)=ACT*GEE+DVZ
C PRESSURE INDUCED BY FREE SURFACE
* PRFS(J)=PRT*GEE*RHOP
* CONTINUE
1500 60 FORMAT(' FREE SURFACE INDUCE PRESSURES')
1070  TYPE 60
      TYPE 1070, (PRFS(J), J=1, NPAN)
      RETURN
      END

```

```

C *** SUBROUTINE CFSR
C *** Advance free surface wave spectra in time
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
* ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
* STOLD(120),PX(120,6)
COMMON/FS/AKZ(100,100),SS(100,100),CC(100,100),
* DKX(100),DKY(100),AKX(100),AKY(100)
COMMON/FS1/A(100,100),B(100,100),AS(100,100),BS(100,100)
COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFWD
DIMENSION CX(100)
COMPLEX EYE,AT,ATS,CX,CY,CXY1,CXYS,A,B,AS,BS,DFWD
DO 100 N=1,NKX
CXX=AKX(N)*UFWD*DT
S=SIN(CXX)
C=COS(CXX)
DFWD=CMPLX(C,-S)
DO 100 M=1,NKY
CT=CC(N,M)
STT=SS(N,M)
AT=A(N,M)*CT+B(N,M)*STT
ATS=AS(N,M)*CT+BS(N,M)*STT
B(N,M)=B(N,M)*CT-A(N,M)*STT
BS(N,M)=BS(N,M)*CT-AS(N,M)*STT
A(N,M)=AT
AS(N,M)=ATS
C MOVE FREE SURFACE RELATIVE TO BODY WITH FWD SPEED
A(N,M)=A(N,M)*DFWD
B(N,M)=B(N,M)*DFWD
AS(N,M)=AS(N,M)*DFWD
BS(N,M)=BS(N,M)*DFWD
100 CONTINUE
6 CONTINUE
C *** Add effects of source panels acting over one time step
DO 1500 J=1,NPAN
STAR=(ST(J)*0.50*DT+STOLD(J))*DT
C ST IS TIME RATE OF CHANGE OF SOURCE STRENGTH
C STOLD IS SOURCE STRENGTH AT START OF TIME STEP
C STAR IS AVERAGE VALUE OF STRENGTH OVER THE TIME STEP
STAR2=STOLD(J)*DT
STAR=STAR*AREA(J)*0.6366197724
STAR2=STAR2*AREA(J)*0.31831
X=XPAN(J)
IF(JTM.GT.0) X=X-UFWD*DT*.5
Y=YPAN(J)
Z=ZPAN(J)
DO 93 N=1,NKX
CXX=AKX(N)*X
S=SIN(CXX)
C=COS(CXX)
93 CX(N)=CMPLX(C,-S)
DO 94 M=1,NKY
CYY=AKY(M)*Y
S=SIN(CYY)
C=COS(CYY)
CY=CMPLX(C,-S)
DO 94 N=1,NKX
ARGZ=AKZ(N,M)*Z
DEP=EXP(-ARGZ)
CXY1=CX(N)*CY*DEP
CXYS=CX(N)*DEP*CONJG(CY)
A(N,M)=A(N,M)+STAR*CXY1
AS(N,M)=AS(N,M)+STAR*CXYS
C B(N,M) AND BS(N,M) INCREMENTED NEGLECTING CHANGES IN
C SOURCE STRENGTHS
C OVER TIME INTERVAL ARE SECOND ORDER IN DT
B(N,M)=B(N,M)-STAR2*CXY1*SS(N,M)
BS(N,M)=BS(N,M)-STAR2*CXYS*SS(N,M)
94 CONTINUE
1500 CONTINUE
RETURN
END

```

```

C *** SUBROUTINE POTB
C   Pressures induced by time rate of change of source
C   strength of panel J in space fixed coordinates
C   COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
*   ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
*   STOLD(120),PX(120,6)
C   COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFWD
C   COMMON/SOURCE/EE(120,120),BPRES(120)
C   COMPLEX EYE
C   DIMENSION PP(6)
C   PP(1)=0.00
C   PP(2)=0.00
C   PP(3)=0.00
C   PP(4)=0.00
C   PP(5)=0.00
C   PP(6)=0.00
C   DO 1500 J=1,NPAN
C ST(J) IS TIME RATE OF CHANGE IN HULL FIXED SYSTEM OF SOURCE STRENGTH
C OF PANEL J
C STAV IS AVERAGE SOURCE STRENGTH OVER TIME STEP AT CENTER OF PANEL J
C STAV=STOLD(J)+0.5*DT*ST(J)
C TIME DERIVATIVE IN SPACE FIXED SYSTEM
C   DO 1200 K=1,6
C   PP(K)=PP(K)+(ST(J)*P(J,K)-STAV*UFWD*PX(J,K))*RHOP
1200  CONTINUE
1500  CONTINUE
C   DO 1800 J=1,NPAN
C   BPRES(J)=(ST(J)*P(J,3)-STAV*UFWD*PX(J,3))*RHOP
C   DENOM=AN(J,3)*AREA(J)
C   IF(DENOM.EQ.0.) THEN
C     BPRES(J)=0.
C   ELSE
C     BPRES(J)=BPRES(J)/DENOM
C   ENDIF
1800  CONTINUE
TYPE *, ' BODY INDUCED PRESSURES'
TYPE 1070,(BPRES(J),J=1,NPAN)
1070  FORMAT(1X,5F16.8)
TYPE *
TYPE 1870
1870  FORMAT(' BODY INDUCED FORCES=')
TYPE 2020,PP(1),PP(2),PP(3),PP(4),PP(5),PP(6)
2020  FORMAT(3X,3F20.6)
RETURN
END

```

```

C
C      SUBROUTINE PRFR(PT)
C *** Computes forces and moments
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
*   ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
*   STOLD(120),PX(120,6)
COMMON/A/NPAN,NPT,GEE,RHOP,NKX,NKY,EYE,DT,TIM,UFWD
DIMENSION PF(6)
COMMON/SOURCE/EE(120,120),BPRES(120)
COMMON/MASS/RHO,G,GAMMA,DISPL,SMASS,XCG,YCG,ZCG
COMMON /          / MSTA,NPROF,NFWD,NAFT,LPTS(25),
1           XOFF(25),YOFF(25,25),ZOFF(25,25),
2           XPROF(51),YPROF(51)

COMPLEX EYE
COMMON/DISPLAY/TARE(6)
X1=0.0
X2=0.0
X3=0.0
X4=0.0
X5=0.0
X6=0.0
XCGAM=XCG-.5*(XOFF(1)-XOFF(MSTA)))
DO 725 J=1,NPAN
TPRES=BPRES(J)+PRFS(J)
PRS=TPRES(J)*AREA(J)
FRX=-AN(J,1)*PRS
FRY=-AN(J,2)*PRS
FRZ=-AN(J,3)*PRS
XF=XPAN(J+XCGAM)
YF=YPAN(J)
ZF=ZPAN(J)+TARE(2)
X1=X1+FRX
X2=X2+FRY
X3=X3+FRZ
X4=X4+YF*FRZ-ZF*FRY
X5=X5+ZF*FRX-XF*FRZ
X6=X6+XF*FRY-YF*FRX
CONTINUE
725
TYPE 80
80 FORMAT(' PRESSURE INDUCED FORCES---')
TYPE 40,X1,X2,X3,X4,X5,X6
PT(1)=X1
PT(2)=X2
PT(3)=X3
PT(4)=X4
PT(5)=X5
PT(6)=X6
40 FORMAT(5X,3F15.7)
RETURN
END

```

```

SUBROUTINE ZBLACN(ACBX, ACBY, ACBZ, ACBRL, ACBP, ACBYW)
C *** Computes source strengths satisfying body b.c.
COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
*, ACN(120), ACNW(120), AN(120, 3), E(120), P(120, 6), PRFS(120),
* STOLD(120), PX(120, 6)
COMMON/A/NPAN, NPT, GEE, RHOP, NKX, NKY, EYE, DT, TIM, UFWD
COMMON/SOURCE/EE(120, 120), BPRES(120)
COMPLEX EYE
DO 1800 J=1, NPAN
X=XPAN(J)
Y=YPAN(J)
Z=ZPAN(J)
ACX=ACBX+ACBP*Z-ACBYW*Y
ACY=ACBY+ACBYW*X-ACBRL*Z
ACZ=ACBZ+ACBRL*Y-ACBP*X
C *** Dot product of body acc. + nrm1 free-surface included
C normal acceleration
ACN(J)=-ACNW(J)+ACX*AN(J, 1)+ACY*AN(J, 2)+ACZ*AN(J, 3)
C *** Integrate time derivative for total source strength
C at start of time step
STOLD(J)=STOLD(J)+DT*ST(J)
ST(J)=0.00
1800 CONTINUE
DO 1500 J=1, NPAN
AC=ACN(J)
DO 1400 K=1, NPAN
ST(K)=ST(K)+EE(J, K)*AC
1400 CONTINUE
1500 CONTINUE
RETURN
END

```

```

C *** CARD TYPE D
30 N=1
MSTA=MSTA+1
IF (MSTA .GT. 25) CALL ERROR(10, IDUM, RDUM)
READ (OFF, 416) STATNO, Y11, Z1, JTEST
WRITE(ECHO, 417) STATNO, Y11, Z1, JTEST
XOFF(MSTA)=STATNO*SPACE
GO TO 50
40 CONTINUE           !loop within each station
N=N+1
IF (N .GT. 25) CALL ERROR(11, MSTA, RDUM)
READ (OFF, 416) S, Y11, Z1, JTEST
WRITE(ECHO, 417) S, Y11, Z1, JTEST
IF (S .NE. STATNO) CALL ERROR(12, MSTA, RDUM)
50 YOFF(N, MSTA)=Z1*ZSCAL
ZOFF(N, MSTA)=Y11*YSCAL
IF (JTEST .EQ. 0 .OR. JTEST .EQ. 77777) GO TO 40
LPTS(MSTA)=N          !No. of points- MSTA
IF (N .LT. 2) CALL ERROR(13, MSTA, RDUM)
IF (JTEST .EQ. 88888) GO TO 30      !Go onto next station
IF (JTEST .NE. 99999) CALL ERROR(14, JTEST, RDUM)

```

```

C
C
C
C-----
```

### C Section 3.0 READ COEFFICIENT FILE

```

READ (COF) MSTA           !Number of Stations
READ (COF) (OM(I), I=1, 12) !Frequency (rad/sec)
READ (COF) (DRAFT1(I), I=1, 6) !DRAFTs
DO 300 L=1, MSTA          !Station index
DO 300 K=1, 6              !DRAFT index
DO 300 J=1, 12             !Frequency index
READ(COF) (COEFF4(K, J, I, L), I=1, 8)
300 CONTINUE
READ (COF) ((AREAN(L, K), K=1, 6), L=1, MSTA) !Section areas
C
C       DO 688 L=1, MSTA
C       TYPE 687, (AREAN(L, K), K=1, 6)
C688  CONTINUE
DO 675 J=1, 6
TARE(J)=POSIT(J)
675 CONTINUE
687 FORMAT(1X, 6F10. 2)

```

```

C
C-----
```

### C Section 4.0 READ 3D ARRAY FILE [MAT]

```

IF(MATFIL .EQ. 'NONE') RETURN
C
READ(MAT) NPT, NPAN
DO 500 I=1, 3
READ(MAT) (AN(J, I), J=1, NPAN)
500 CONTINUE
READ(MAT) (XPAN(J), J=1, NPAN)
READ(MAT) (YPAN(J), J=1, NPAN)
READ(MAT) (ZPAN(J), J=1, NPAN)
READ(MAT) (AREAP(J), J=1, NPAN)
DO 505 K=1, 6
READ(MAT) (PX(JL, K), JL=1, NPAN)
505 CONTINUE
DO 510 J=1, NPAN
READ(MAT) (EE(J, K), K=1, NPAN)
510 CONTINUE
DO 520 K=1, 6
READ(MAT) (P(J, K), J=1, NPAN)
520 CONTINUE
C
CLOSE(BIF)
CLOSE(OFF)
CLOSE(COF)
CLOSE(MAT)
CLOSE(4)
RETURN
180 FORMAT (5X, I5)
190 FORMAT (I5)
197 FORMAT(1H1/, 81(1H*)/, ' INPUT DATA ECHO ', T64,
```

```

* 'PROGRAM SSX', 81(1H*)//,33(1H-),
* '[BIF] DATA FILE', 32(1H-)/
198 FORMAT(1H1/, 81(1H*)/, ' INPUT DATA ECHO ', T64,
* 'PROGRAM SSX', 81(1H*)//,33(1H-),
* '[COFF] DATA FILE', 32(1H-)/)
196 FORMAT(1X,A)
199 FORMAT(A)
200 FORMAT (6F10. 2)
201 FORMAT (3F10. 2, I5)
202 FORMAT (8F10. 0)
203 FORMAT (I2)
210 FORMAT (F10. 2, I5, 5X, F10. 2)

C
410 FORMAT (A)
412 FORMAT (4F10. 3, 13X, I2, 4X, I1)
414 FORMAT (5X, I5, 5X, 'INPUT OF SHCP TYPE D OFFSET DATA')
416 FORMAT (F6. 3, 2F7. 0, I6)
417 FORMAT (F7. 3, 2F10. 2, I6)
420 FORMAT (2I5, F10. 2)
430 FORMAT (2F10. 2)

C
END

C
SUBROUTINE FINI

COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON /STATS / NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1
COMMON /TIME / TIME, RAMP
COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/SUMMARY/ NT, YYBAR(10), YYRMS(10), YYMAX(10), YYMIN(10)
IF (TT1.LE.TTO) GO TO 100
DELTA=TT1-TTO
NRHS(1)=NRHS(1)+1
HMIN=AMIN1(DELTA, HMIN)
HMAX=AMAX1(DELTA, HMAX)
100 HSUM=HSUM/FLOAT(NRHS(1))
C *** Print execution statistics
WRITE (OUTPUT, 110) NRHS, DELTA, HMIN, HSUM, HMAX, TSTEP, ERR
C *** Compute response statistics
DO 200 I=1, 10
YYBAR(I)=YYBAR(I)/FLOAT(NT)
ARGI=(YYRMS(I)/FLOAT(NT)-YYBAR(I)**2)
IF(ARGI.LT.0) YYRMS(I)=0.
IF(ARGI.GE.0.) YYRMS(I)=SQRT(ARGI)
200 YYRMS(I)=SQRT(YYRMS(I)/NT-YYBAR(I)**2)
CONTINUE
C *** Print response statistics
WRITE(OUTPUT, 201) ' RMS      ', YYRMS
WRITE(OUTPUT, 201) ' MEAN     ', YYBAR
WRITE(OUTPUT, 201) ' MAX      ', YYMAX
WRITE(OUTPUT, 201) ' MIN      ', YYMIN
C
RETURN
C
110 FORMAT (76H0*** TIME INCREMENT : FWD NO STE
$P      BACK TOTAL/
$      36H *** NUMBER OF COMPUTATIONS OF RHS :, 4I10/36H *** FINAL V
1ALUE OF TIME INCREMENT :, 1PG13. 4/38H *** MINIMUM VALUE OF TIME INC
2REMENT :, G13. 4/38H *** AVERAGE VALUE OF TIME INCREMENT :, G13. 4/38H
3 *** MAXIMUM VALUE OF TIME INCREMENT :, G13. 4/42H *** FLAG VALUE, F
4I, (PLUS 1.0 EXPECTED) :, G13. 4/33H *** FINAL VALUE OF ERROR LIMIT
5:, G13. 4)

C
C
201 FORMAT(A8, 4X, 4(1X, F11. 4), 3F12. 4, 2X, E15. 5, 2X, F12. 4)
C
END

```

SUBROUTINE PREPARE

```

C-----  

COMMON /C      / C(3,3)  

COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF  

INTEGER OUTPUT,BIF,OFF,COF  

COMMON /      / NWAVES, WVSUM,  

1           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),  

2           WN(20), WNX(20), WNZ(20),  

3           CSK(20), CCK(20), CXK(20),  

4           CYK(20), CZK(20), XW(20)  

COMMON /      / MSTA, NPROF, NFWD, NAFT, LPTS(25),  

1           XOFF(25), YOFF(25,25), ZOFF(25,25),  

2           XPROF(51), YPROF(51)  

COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)  

COMMON /FORCE / XF, YF, ZF, XM, YM, ZM  

REAL  FORCE(6)  

EQUIVALENCE (FORCE(1),XF)  

COMMON /LHS  / Y(13)  

COMMON /MASS / RHO, G, GAMMA  

COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,  

1           AMX, AMY, AMZ, RADII(6)  

COMMON /MASS / PMI(3,3)  

COMMON /RESIST/ SPEED  

COMMON /TIME / TIME, RAMP  

COMMON /TIME / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR  

COMMON /V   / VX, VY, VZ  

COMMON/PREXIN/TPSTART, TPSTOP, TPRAMP, BGX, SMX, BGY, SMY, TSCALE  

REAL  XAFT(25), YAFT(25), XFWD(25), YFWD(25)  

EQUIVALENCE (XAFT(1),XPROF(1)), (YFWD(1),YPROF(1))  

EQUIVALENCE (XAFT(1),XPROF(26)), (YAFT(1),YPROF(26))  

EQUIVALENCE (XXFWD,XPROF(51)), (XXAFT,YPROF(51))  

COMMON/SXPROP/ SEGMAS(26),SEGMDX(26),STRMAS(26),STRMOM(26),  

*           STRMOX(26),XBAR(26),YBAR(26),  

*           SEGWT(26),NWTSTA  

* DATA MAXSTA/25/  

* DATA MAXPTS/25/  

* DATA AMX/O. /,AMY/O. /,AMZ/O. /  

* DATA RAD  /0.01745 32925 19943/  

* GAMMA=RHO*G  

* SMASS=DISPL/G  

* DISPL=DISPL/GAMMA  

* RAMP=TSTART-TO  

* AMX=1. O+AMX  

* AMY=1. O+AMY  

* AMZ=1. O+AMZ  

C-----  

C *** From given offsets on port side, assign symmetrical  

C     offsets on starboard side  

DO 10 J=1,MSTA  

  N=LPTS(J)  

  NP=N  

  DO 50 I=1,N  

    NP=NP+1  

    NM=N-I+1  

    YOFF(NP,J)=YOFF(NM,J)  

    ZOFF(NP,J)=-ZOFF(NM,J)  

50  CONTINUE  

60  IF (ZOFF(NP,J).NE.ZOFF(1,J)) GO TO 70  

    IF (YOFF(NP,J).EQ.YOFF(1,J)) GO TO 80  

70  NP=NP+1  

    YOFF(NP,J)=YOFF(1,J)  

    ZOFF(NP,J)=ZOFF(1,J)  

80  IF (NP.GT.MAXPTS) GO TO 90  

    IF (NP.GT.1) GO TO 20  

90  CONTINUE  

20  STOP 'ERROR'  

10  LPTS(J)=NP  

10  CONTINUE  

C-----  

C *** Recompute offset coordinates relative to the center of mass  

DO 130 J=1,MSTA  

  XOFF(J)=-XOFF(J)-XCG  

  N=LPTS(J)  

  DO 120 I=1,N  

    YOFF(I,J)=YOFF(I,J)-YCG  

    ZOFF(I,J)=ZOFF(I,J)-ZCG  

120  CONTINUE  

130 CONTINUE

```

```

C *** Consolidate fore & aft profile coordinates into a single
C pair of arrays
NPROF=NFWD
IF (NFWD, EQ. 0) GO TO 150
X=XOFF(1)
DO 140 I=1, NFWD
  XFWD(I)=XFWD(I)+X
  YFWD(I)=YFWD(I)-YCG
140 CONTINUE
IF (NFWD, NE. 1) GO TO 150
NPROF=0
XXFWD=XFWD(1)
150 IF (NAFT, EQ. 0) GO TO 190
X=XOFF(MSTA)
XXAFT=X-XAFT(1)
IF (NAFT, EQ. 1) GO TO 190
J=1
IF (NPROF, EQ. 0) GO TO 160
IF (XXAFT, NE. XFWD(NPROF)) GO TO 160
IF (YPROF(NPROF), EQ. (YAFT(1)-YCG)) J=2
160 DO 170 I=J, NAFT
  NPROF=NPROF+1
  XPROF(NPROF)=X-XXAFT(I)
  YPROF(NPROF)=YAFT(I)-YCG
170 CONTINUE
IF (XFWD(1), NE. XFWD(NPROF)) GO TO 180
IF (YFWD(1), EQ. YFWD(NPROF)) GO TO 190
180 NPROF=NPROF+1
XFWD(NPROF)=XFWD(1)
YFWD(NPROF)=YFWD(1)
190 CONTINUE
C
C *** This section loads certain strip-associated mass and inertial
C arrays using mass/inertial data from segment-associated arrays
C *** Load strip & segment associated inertial arrays
DO 106 I=1, NWTSTA
  SEGMAS(I)=SEGWT(I)/G
106 CONTINUE
VX=SPEED
C
C *** Load the inertia matrix
PMI(1,1)=SMASS*RADI(1)**2
PMI(2,2)=SMASS*RADI(2)**2
PMI(3,3)=SMASS*RADI(3)**2
PMI(2,1)=-ABS(RADI(4))*RADI(4)*SMASS
PMI(1,2)=PMI(2,1)
PMI(3,1)=-ABS(RADI(5))*RADI(5)*SMASS
PMI(1,3)=PMI(3,1)
PMI(2,3)=-ABS(RADI(6))*RADI(6)*SMASS
PMI(3,2)=PMI(2,3)
C
C *** Compute wave no's and max wave amplitude
WVSUM=0.0
IF (NWAVES, EQ. 0) GO TO 260
DO 250 K=1, NWAVES
  WVPHA(K)=RAD*WVPHA(K)
  WN(K)=WVFRE(K)**2/G
  ARG=WVDIR(K)*RAD
  WNX(K)=WN(K)*COS(ARG)
  WNZ(K)=WN(K)*SIN(ARG)
  WVSUM=WVSUM+ABS(WVAMP(K))
250 CONTINUE
260 CONTINUE
C
C *** Convert degrees to radians
DO 270 I=4, 6
  Y(I)=Y(I)*RAD
  Y(I+6)=Y(I+6)*RAD
270 CONTINUE
C
C *** Convert initial linear velocities from ship coordinates
C fixed coordinates.
CALL ROTATE (Y)
VX=Y(7)
VY=Y(8)
VZ=Y(9)
Y(7)=C(1,1)*VX+C(2,1)*VY+C(3,1)*VZ
Y(8)=C(1,2)*VX+C(2,2)*VY+C(3,2)*VZ
Y(9)=C(1,3)*VX+C(2,3)*VY+C(3,3)*VZ
C

```

```
C *** Divide all 2-D hydro. coeffs by RHO
DO 110 L=1,MSTA
DO 110 K=1,6
DO 110 J=1,12
DO 110 I=1,8
COEFF4(K,J,I,L)=COEFF4(K,J,I,L)/RHO
110 CONTINUE
C *** Initialize the free surface for special pressure
C computations
C IF(TPSTOP.GT.5.) CALL AFSR
C
RETURN
END
```

```

      SUBROUTINE LUFFEE

CCC      COMMON/MASS/RHO, G, GAMMA
CCC      COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,
CCC          *           AMX, AMY, AMZ, RADII(6)
CCC          *           COMMON/LHS/Y(13)
C5       WAVE PROPERTIES. .
COMMON /           NWAVES, WVSUM,
1           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2           WN(20), WNX(20), WNZ(20),
3           CSK(20), CCK(20), CXK(20),
4           CYK(20), CZK(20), XW(20)

C5
C5
C5   TABLE OF OFFSETS. .
COMMON /           MSTA, NPROF, NFWD, NAFT, LPTS(25),
1           XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2           XPROF(51), YPROF(51)

COMMON/RESIST/SPEED
COMMON/SIGMA / NK, SIGMA(24), SIGMA0, ERRO, DM(12)

C
C
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON/COEFFX/THAH(25, 21), TSAS(25, 21), TRAR(25, 21), TCCA(25, 21),
*           THVH(25, 21), TSVS(25, 21), TRVR(25, 21), TCCV(25, 21),
*           THACX(25, 21), THVCX(25, 21), TSACX(25, 21), TSVCX(25, 21),
*           TRACX(25, 21), TCACX(25, 21), THVCY(25, 21),
*           ITP(25), TXP(25), IFP(21), FXP(21)
COMMON/OPTION/JBCO, JOBF0(10)
COMMON/SXOMEG/OMEGAX(3)
COMMON/DRFT1/ DRAFT1(6)

C
DIMENSION LIX(21), FMUX(21)
DATA DEGREE/0.01745 32925/
C
CCC
CCC (Future revision here... no trim now, but in
CCC next revision, the options should include
CCC specifying trim [Y(6)] in addition to draft
CCC as an initial condition)
CCC
      TAVG=YCG-Y(2)                                !Draft
      TYPE *, 'TAVG=', TAVG
      DO 20 JSTA=1, MSTA                           !Loop over stations
      CALL TXIT(TAVG, IT, TX)                      !Get index & mult.
      ITP(JSTA)=IT
      TXP(JSTA)=TX
      TYPE *, 'IT, TX', IT, TX

CCC
      DO 10 K=1, NWAVES
CCC
      *           FREX=ABS((1.0-COS(WVDIR(K)*DEGREE)*SPEED
      *           *WVFRE(K)/G)*WVFRE(K))           !Encounter freq.
      TYPE *, 'Encounter freq=', FREX

C
C-----  

C
C     NOTE: We are using the wave frequency here-- not the
C           frequency of encounter.

```

```

C      FREX=WVFRE(K)
C-----  

C      CALL FXIF(FREX, IF, FX)          !Get index & mult.  

CCC  

C      IFP(K)=IF  

C      FXP(K)=FX  

C      THAH(JSTA,K)=COX(IT, TX, IF, FX, 1, JSTA)  

C      TSAS(JSTA,K)=COX(IT, TX, IF, FX, 2, JSTA)  

C      TRAR(JSTA,K)=COX(IT, TX, IF, FX, 3, JSTA)  

C      TCCA(JSTA,K)=COX(IT, TX, IF, FX, 4, JSTA)  

C  

C      THVH(JSTA,K)=COX(IT, TX, IF, FX, 5, JSTA)  

C      TSVS(JSTA,K)=COX(IT, TX, IF, FX, 6, JSTA)  

C      TRVR(JSTA,K)=COX(IT, TX, IF, FX, 7, JSTA)  

C      TCCV(JSTA,K)=COX(IT, TX, IF, FX, 8, JSTA)  

C  

C      Spatial derivatives in x-direction  

C  

C      THACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 1, JSTA)  

C      TSACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 2, JSTA)  

C      TRACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 3, JSTA)  

C      TCACX(JSTA,K)=COXDXP(IT, TX, IF, FX, 4, JSTA)  

C  

C      THVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 5, JSTA)  

C      TSVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 6, JSTA)  

C      TRVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 7, JSTA)  

C      TCVCX(JSTA,K)=COXDXP(IT, TX, IF, FX, 8, JSTA)  

C  

10    CONTINUE  

20    CONTINUE  

C  

CCC  

CCC      For ship motion related hydro coef's, we will  

CCC      use, as a default frequency the frequency associated  

CCC      with the first wave [wvfre(1)].  

CCC  

CCC      Future revision: the default frequencies should  

CCC      be the natural period in heave, sway, and roll.  

CCC  

C      FRSI=ABS((1.0-COS(WVDIR(1)*DEGREE)*SPEED  

*           *WVFRE(1)/G)*WVFRE(1))          !Encounter freq.  

C      OMEGAX(1)=FRSI  

C      OMEGAX(2)=FRSI  

C      OMEGAX(3)=FRSI  

C  

C      CALL FXIF(FRSI, IF, FX)  

C  

C      DO 30 JSTA=1, MSTA  

C  

C      FXP(21)=FX  

C      IFP(21)=IF  

C      TXP(21)=TX  

C      ITP(21)=IT  

C  

C      THAH(JSTA,21)=COX(IT, TX, IF, FX, 1, JSTA)  

C      TSAS(JSTA,21)=COX(IT, TX, IF, FX, 2, JSTA)  

C      TRAR(JSTA,21)=COX(IT, TX, IF, FX, 3, JSTA)

```

```

C TCCA(JSTA, 21)=COX(IT, TX, IF, FX, 4, JSTA)
C THVH(JSTA, 21)=COX(IT, TX, IF, FX, 5, JSTA)
C TSVS(JSTA, 21)=COX(IT, TX, IF, FX, 6, JSTA)
C TRVR(JSTA, 21)=COX(IT, TX, IF, FX, 7, JSTA)
C TCCV(JSTA, 21)=COX(IT, TX, IF, FX, 8, JSTA)
C THACX(JSTA, 21)=COXDXP(IT, TX, IF, FX, 1, JSTA)
C TSACX(JSTA, 21)=COXDXP(IT, TX, IF, FX, 2, JSTA)
C THVCX(JSTA, 21)=COXDXP(IT, TX, IF, FX, 5, JSTA)
C TSVCX(JSTA, 21)=COXDXP(IT, TX, IF, FX, 6, JSTA)
C 30 CONTINUE
C RETURN
C END
C FUNCTION COX(IT, TX, IF, FX, ITYPE, JSTA)
CCC
CCC This function subprogram returns the 2-D hydrodynamic
CCC coefficient of a particular TYPE (1 thru 8 where 1 is
CCC HAH, 2 is SAS, and so on) keyed on ITYPE; for a par-
CCC ticular station, keyed on JSTA. Provided to the function
CCC is the draft index (IT) and draft interpolation multi-
CCC plier, the frequency index (IF) and the frequency inter-
CCC polation multiplier (FX).
CCC
CCC This function performs a two-dim linear interpolation
CCC using four values from the big 2-D coefficient array
CCC COEFF4( , , , , )...
CCC
CCC COMMON /COEFF4/ COEFF4(6, 12, 8, 25), AREAN(25, 6)
CCC
CCC A1=COEFF4(IT, IF, ITYPE, JSTA)
CCC A2=COEFF4(IT+1, IF, ITYPE, JSTA)
CCC A3=COEFF4(IT, IF+1, ITYPE, JSTA)
CCC A4=COEFF4(IT+1, IF+1, ITYPE, JSTA)
CCC
CCC B12=A1+(TX*(A2-A1))
CCC B34=A3+(TX*(A4-A3))
CCC
CCC COX=B12+(FX*(B34-B12))
CCC
CCC RETURN
CCC END
CCC SUBROUTINE TXIT(TAVG, IT, TX)
CCC
CCC This routine determines the draft index (IT)
CCC and draft interpolation multiplier (TX) given
CCC a value for draft (TAVG).
CCC
CCC COMMON/DRFT1/ DRAFT1(6)
CCC
CCC IF (TAVG.GT.DRAFT1(6)) THEN !Section immersed
CCC   IT=5
CCC   TX=1.0
CCC ELSE IF (TAVG.LT.DRAFT1(1)) THEN !Emerged section
CCC   IT=1
CCC   TX=0.0
CCC ELSE
CCC   DO 10 JJ=2, 6
CCC   IF (TAVG-DRAFT1(JJ)) 12, 11, 10
CCC   CONTINUE

```

```

IT=JJ
GO TO 13
CONTINUE
TX=(TAVG-DRAFT1(JJ-1))/(DRAFT1(JJ)-DRAFT1(JJ-1))
IT=JJ-1
GO TO 13
CONTINUE
CONTINUE
END IF
RETURN
END
SUBROUTINE FXIF(FREX, IF, FX)

```

This routine determines the freq. index (IF) and freq. interpolation multiplier (FX) given a value for frequency (FREX).

```

COMMON /SIGMA/ NK, SIGMA(24), SIGMAO, ERRC, OM(13
IF (FREX.GT.OM(11)) THEN
  IF=11
  FX=1.0
ELSE
  DO 10 JJ=2, 12
  IF(FREX-OM(JJ)) 12, 11, 10
  CONTINUE
  FX=0.0
  IF=JJ
  GO TO 13
  CONTINUE
  FX=(FREX-OM(JJ-1))/(OM(JJ)-OM(JJ-1))
  IF=JJ-1
  GO TO 13
  CONTINUE
  CONTINUE
END IF
RETURN
END
FUNCTION COXDX(IT, TX, IF, FX, L, J)

```

```

COMMON /      / NWAVES, WVSUM,
1          / WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          / WN(20), WNX(20), WNZ(20),
3          / CSK(20), CCK(20), CXK(20),
4          / CYK(20), CZK(20), XW(20)
COMMON /      / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1          / XDFF(25), YOFF(25,25), ZOFF(25,25),
2          / XPROF(51), YPROF(51)
COMMON/OPTION/JBCO, JOBF0(10)
COMMON/ETA/YC, XK(20)
COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)

```

---

```

IF(J.EQ.1) THEN
  CF=0.
ELSE
  CF=COX(IT, TX, IF, FX, L, J-1)
  AF=ARX(IT, TX, J-1)

```

```

CF=CF*AF
END IF
C
      CM=COX(IT, TX, IF, FX, L, J)
      AM=ARX(IT, TX, J)
      CM=CM*AM
C
      IF(J.EQ.MSTA) THEN
          CA=0.
      ELSE
          CA=COX(IT, TX, IF, FX, L, J+1)
          AA=ARX(IT, TX, J+1)
          CA=CA*AA
      END IF
C
      C1=(CM-CF)/DXFWD
      C2=(CA-CM)/DXAFT
C
      CODXD=(.5/AM)*(C1+C2)
C
      RETURN
END
FUNCTION CODXDP(IT, TX, IF, FX, L, J)
C
COMMON /      / NWAVES, WVSUM,
1           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2           WN(20), WNX(20), WNZ(20),
3           CSK(20), CCK(20), CXK(20),
4           CYK(20), CZK(20), XW(20)
COMMON /      / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1           XOFF(25), YOFF(25,25), ZOFF(25,25),
2           XPROF(51), YPROF(51)
C
C-----C
C
      IF(J.EQ.1) THEN
          CF=0.
          DXFWD=XOFF(J+1)-XOFF(J)
      ELSE
          CF=COX(IT, TX, IF, FX, L, J-1)
          AF=ARX(IT, TX, J-1)
          CF=CF*AF
          DXFWD=XOFF(J)-XOFF(J-1)
      END IF
C
      CM=COX(IT, TX, IF, FX, L, J)
      AM=ARX(IT, TX, J)
      CM=CM*AM
C
      IF(J.EQ.MSTA) THEN
          CA=0.
          DXAFT=XOFF(J)-XOFF(J-1)
      ELSE
          CA=COX(IT, TX, IF, FX, L, J+1)
          AA=ARX(IT, TX, J+1)
          CA=CA*AA
          DXAFT=XOFF(J+1)-XOFF(J)
      END IF
C
      C1=(CM-CF)/DXFWD

```

```
C2=(CA-CM)/DXAFT
C
COXDXP=(.5/AM)*(C1+C2)
TDX=DXFWD+DXAFT
DCX=CA-CF
COXDXP=(DCX/TDX)/AM
C
RETURN
END
FUNCTION ARX(IT, TX, J)
COMMON /COEFF4/ COEFF4(6, 12, 8, 25), AREAN(25, 6)
CCC
CCC
CCC
B2=AREAN(J, IT+1)
B1=AREAN(J, IT)
ARX=B1+(TX*(B2-B1))
CCC
RETURN
END
```

FUNCTION ETABAR(I)

C  
C1 ETABAR RETURNS THE WAVE ELEVATION (ABSOLUTE COORDINATES) ABOVE  
C1 A POINT IN THE SHIP COORDINATE SYSTEM.  
C1

C2 POINT IS ON THE SHIP CENTERPLANE.

C2 THE COORDINATES OF THE POINT ON THE SHIP ARE..  
C2 ( XPROF(I), YPROF(I), -ZCG )  
C2

C5 PHYSICAL CONSTANTS.

C5 COMMON /MASS / RHO, G, GAMMA  
C5

C5 SHIP MASS PARAMETERS.

C5 COMMON /MASS / DISPL, SMASS, XCG, YCG, ZCG,  
1 AMX, AMY, AMZ, RADII(6)  
C5

C5 ROTATIONAL INERTIA MATRIX FOR FIXED MASS..

C5 COMMON /MASS / PMI(3,3)  
C5

C5 COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI  
C5

C5 WAVE PROPERTIES..

C5 COMMON / / NWAVES, WVSUM,  
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),  
2 WN(20), WNX(20), WNZ(20),  
3 CSK(20), CCK(20), CXK(20),  
4 CYK(20), CZK(20), XW(20)  
C5

C5 TABLE OF OFFSETS..

C5 COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),  
1 XOFF(25), YOFF(25,25), ZOFF(25,25),  
2 XPROF(51), YPROF(51)  
C5

C3 ETABAR=0.0

IF (NWAVES, EQ. 0) RETURN

X1=XPROF(I)

Y1=YPROF(I)\*CTHETA+ZCG\*STHETA

Z1=YPROF(I)\*STHETA-ZCG\*CTHETA

DO 110 K=1,NWAVES

ARG=(X1-XW(K))\*CXK(K)+Y1\*CYK(K)+Z1\*CZK(K)

ETABAR=COS(ARG)\*WVAMP(K)+ETABAR

110 CONTINUE

RETURN

C END

FUNCTION ETAF (ZT)

C1 FIND COORDINATE OF WAVE SURFACE.  
C1

C5 WAVE PROPERTIES..

C5 COMMON / / NWAVES, WVSUM,  
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),  
2 WN(20), WNX(20), WNZ(20),  
3 CSK(20), CCK(20), CXK(20),  
4 CYK(20), CZK(20), XW(20)  
C5

```

C5      DATA FOR THE COMPUTATION OF THE WAVE SURFACE ELAVATION..
COMMON /ETA    /  YC, XK(20)
C5      COMMON /CT     /  CT(3,3)
C3
A=-YC
B=CT(2,2)
IF (NWAVES.EQ.0) GO TO 120
DO 110 K=1,NWAVES
  ARG=ZT*CZK(K)+XK(K)
  A=COS(ARG)*WVAMP(K)+A
  B=SIN(ARG)*WVAMP(K)*CYK(K)+B
110 CONTINUE
120 ETAF=A/B
RETURN
C
END
FUNCTION ETAY(J,K)
COMMON /TRIG   /  CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /          /  NWAVES, WVSUM,
1          /  WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          /  WN(20), WNX(20), WNZ(20),
3          /  CSK(20), CCK(20), CXK(20),
4          /  CYK(20), CZK(20), XW(.0)
COMMON /          /  MSTA, NPROF, NFWD, NAFT, LPTS(25),
1          /  XOFF(25), YOFF(25,25), ZOFF(25,25),
2          /  XPROF(51), YPROF(51)
ETAY=0.
IF (NWAVES.EQ.0) RETURN
X1=XOFF(J)
Y1=0.
Z1=0.
ARG=(X1-XW(K))*CXK(K)+Y1*CYK(K)+Z1*CZK(K)
ETAY=COS(ARG)*WVAMP(K)
RETURN
C
END

```

C SUBROUTINE FOLIO1

```

COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON/DRFT1/DRAFT1(6)
COMMON/IOFILE/ OFFIL,BIFIL,COFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON /           / NWAVES, WVSUM,
1           /           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2           /           WN(20), WNX(20), WNZ(20),
3           /           CSK(20), CCK(20), CXK(20),
4           /           CYK(20), CZK(20), XW(20)
COMMON /           / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1           /           XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2           /           XPROF(51), YPROF(51)
COMMON /DAMP  / DAMPL(6), DAMPG(6)
COMMON /LHS   / Y(13)
COMMON /MASS  / RHO, G, GAMMA
COMMON /MASS  / DISPL, SMAS, XCG, YCG, ZCG,
1           /           AMX, AMY, AMZ, RADII(6)
COMMON /MASS  / PMI(3, 3)
COMMON /RESIST/ SPEED
COMMON/OPTION/JOBCO, JOBFO(10)
COMMON /TIME  / TIME, RAMP
COMMON /TIME  / TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMOM(26),
*           STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
REAL POSIT(6), VELOC(6)
EQUIVALENCE (POSIT(1), Y(1)), (VELOC(1), Y(7))

```

C

```

WEIGHT=SMASS*G
WRITE(OUTPUT, 100) TITLE
WRITE(OUTPUT, 110) WEIGHT, RADII(1), RADII(2), XCG, RADII(3),
*                   YCG, RADII(4), ZCG, RADII(5), RADII(6)

```

```

* WRITE(OUTPUT, 120) DAMPL(1), DAMPG(1), SPEED,
*                   (DAMPL(I), DAMPG(I), I=2, 6)
* WRITE(OUTPUT, 130) (POSIT(I), VELOC(I), I=1, 6)
WRITE(OUTPUT, 140) TSTART, TSTOP, TOUTPT, TSTEP
WRITE(OUTPUT, 160) RHO, G
WRITE(OUTPUT, 165) JOBCO, (JOBFO(I), I=1, 3)
WRITE(OUTPUT, 100) TITLE
WRITE(OUTPUT, 150)
DO 10 I=1, NWAVES

```

```

10   WRITE(OUTPUT, 155) I, WVAMP(I), WVFRE(I), WVDIR(I), WVPHA(I)
CONTINUE

```

```

WRITE(OUTPUT, 170)
DO 20 I=1, NWTSTA

```

```

20   WRITE(OUTPUT, 175) I, SEGWT(I), SEGMOX(I), YBAR(I)
CONTINUE

```

```

WRITE(OUTPUT, 100) TITLE

```

```

100  FORMAT(1H1, 80(1H=)//, 1X, A, T55, 'PROGRAM SSX (Version 1.0)//',
*81(1H=)//)
110  FORMAT(28(1H-), 'Inertial Characteristics', 29(1H-)/,
*                   T48, 9(1H-), 'GYRADII', 8(1H-)//,
*                   T5, 'WEIGHT', F15.2, 2X, 'L. TONS', T48, 'Kxx', 4X, F10.3, 5X, 'ft',//,
*                   T48, 'Kyy', 4X, F10.3, 5X, 'ft',//,
*                   T5, 'XCG', 10X, F10.3, 4X, 'ft', T48, 'Kzz', 4X, F10.3, 5X, 'ft'//,

```

```

*T5, 'YCG', 10X, F10. 3, 4X, 'ft', T48, 'Kxy', 4X, F10. 3, 5X, 'ft',//,
*T5, 'ZCG', 10x, F10. 3, 4x, 'ft', T48, 'Kxz', 4X, F10. 3, 5X, 'ft',//,
*T5, '-----', 4X, '-----', 5X, '-----',//,
*T5, 'SURGE', 2(5X, E10. 4), T48, 'SPEED', 5X, F6. 2//,
*T5, 'HEAVE', 2(5X, E10. 4)//,
*T5, 'SWAY ', 2(5X, E10. 4)//,
*T5, 'RDL', 2(5X, E10. 4)//,
*T5, 'YAW ', 2(5X, E10. 4)//,
*T5, 'PITCH', 2(5X, E10. 4)///
120 FORMAT(T5, 8(1H-), 'DAMPING COEFFICIENTS', 8(1H-), T48,
*      ,----OPS DATA----'',
*13X, '(user specified)'',
*T5, 'MOTION', 7X, 'LINEAR', 7X, 'QUADRATIC',//,
*T5, '-----', 4X, '-----', 5X, '-----',//,
*T5, '-----', 2(5X, E10. 4), T48, '-----', 5X, F6. 2//,
*T5, '-----', 2(5X, E10. 4)//,
130 FORMAT(32(1H-), 'Initial Conditions', 31(1H-)//,
*T5, 11(1H-), 'POSITION', 11(1H-), T48, 10(1H-), 'VELOCITY', 10(1H-)//,
*T5, 'X(CG)', 11X, F10. 3, 2X, 'ft', T48, 'SPEED', 5X, F10. 3, 2X, 'ft/sec',//,
*T5, 'Y(CG)', 11X, F10. 3, 2X, 'ft', T48, 'HEAVE', 5X, F10. 3, 2X, 'ft/sec',//,
*T5, 'Z(CG)', 11X, F10. 3, 2X, 'ft', T48, 'SWAY ', 5X, F10. 3, 2X, 'ft/sec',//,
*T5, 'RDL', 11X, F10. 3, 1X, 'deg', T48, 'ROLL', 6X, F10. 3, 2X, 'deg/sec',//,
*T5, 'YAW ', 11X, F10. 3, 1X, 'deg', T48, 'YAW', 7X, F10. 3, 2X, 'deg/sec',//,
*T5, 'PITCH', 11X, F10. 3, 1X, 'deg', T48, 'PITCH', 5X, F10. 3, 2X,
*'deg/sec'///
140 FORMAT(34(1H-), 'Run Parameters', 33(1H-)//,
*T5, 'SIMULATION PARAMETERS', T48, 'JOB OPTIONS',//,
*T5, 21(1H-), T48, 11(1H-)//,
*T5, 'TIME(START)', 3X, F8. 2//,
*T5, 'TIME(END)', 5X, F8. 2//,
*T5, 'OUTPUT DT', 5X, F8. 2//,
*T5, 'INTEG. DT', 5X, F8. 2/, 81(1H-)//,
150 FORMAT(33(1H-), 'WAVE COMPONENTS', 33(1H-)//,
*T5, 'WAVE', 5X, 'AMPLITUDE', 5X, 'FREQUENCY', 5X, 'DIRECTION',
*5X, 'PHASE',//,
*T5, '-----', 5X, '-----', 5X, '-----', 5X, '-----',
*5X, '-----')
155 FORMAT(T7, I2, T16, F6. 2, T30, F6. 2, T44, F7. 2, T55, F7. 2)
160 FORMAT(//31(1H-), 'MISCELLANEOUS VALUES', 30(1H-)//,
*T5, 'RHO', 5X, F10. 6/, T5, 'G ', 5X, F10. 6)
165 FORMAT(T5, 'JOBCO', I2/, T5, 'JOBFO', 4I4//)
170 FORMAT(27(1H-), 'SECTIONAL WEIGHT PROPERTIES', 27(1H-)//,
*T5, 'SECTION', 5X, 'WEIGHT', 5X, 'Kxx ', 5X, 'Centroid',//,
*T5, '-----', 5X, '-----', 5X, '-----', 5X, '-----'//)
175 FORMAT(T5, 3X, I2, T13, F10. 3, T26, F8. 2, T39, F8. 2)
RETURN
END

```

```

SUBROUTINE RKF (TIME, Y, TNEXT, ERR, NEQS, STEP)
C
C RUNGE-KUTTA INTEGRATION FOR CAPSIZE.
C
REAL Y(1)
REAL YY(13), YA(13), YB(13)
C-----  

REAL YC(13)
DATA YC(13)/0.0/
C
DATA YY(13)/0.0/
DATA YA(13)/0.0/
DATA YB(13)/0.0/
C
STEP=ABS(STEP)
NSTEP=(TNEXT-TIME)/STEP+0.5
IF (NSTEP.LT.1) NSTEP=1
TSTEP=(TNEXT-TIME)/FLOAT(NSTEP)
HALF=TSTEP/2.0
FACT=TSTEP/6.0
110 CALL DERIV (TIME, Y, YA)
DO 120 I=1, NEQS
  YY(I)=HALF*YA(I)+Y(I)
120 CONTINUE
TIME=HALF+TIME
CALL DERIV (TIME, YY, YB)
DO 130 I=1, NEQS
  YA(I)=2.0*YB(I)+YA(I)
  YY(I)=HALF*YB(I)+Y(I)
130 CONTINUE
CALL DERIV (TIME, YY, YB)
DO 140 I=1, NEQS
  YA(I)=2.0*YB(I)+YA(I)
  YY(I)=TSTEP*YB(I)+Y(I)
140 CONTINUE
TIME=HALF+TIME
CALL DERIV (TIME, YY, YB)
DO 150 I=1, NEQS
  Y(I)=(YA(I)+YB(I))*FACT+Y(I)
150 CONTINUE
C-----  

C This call to DERIV is to get actual acceleration for the
C new TIME. By calling RHS this time we are loading the
C acceleration array ACC( ) in COMMON ACCEL with correct
C accelerations, rather than accel. computed as dictated
C by the fourth-order RUNGA-KUTTA scheme.
C
CALL DERIV(TIME, Y, YC)
CALL GETFREQ
C-----  

IF (TIME+HALF.LT.TNEXT) GO TO 110
TIME=TNEXT
RETURN
END

```

```

SUBROUTINE DERIV (TT, YY, YYDOT)
C Evaluates derivatives in equations of motion
C-----  

C TT -- TIME, THE INDEPENDENT VARIABLE  

C YY -- DEPENDENT VARIABLE ARRAY.  

C YY(1) = X-COORDINATE OF MASS CENTER  

C YY(2) = Y-COORDINATE OF MASS CENTER  

C YY(3) = Z-COORDINATE OF MASS CENTER  

C YY(4) = THETA ROTATION (ROLL ANGLE)  

C YY(5) = PHI ROTATION (YAW ANGLE)  

C YY(6) = PSI ROTATION (PITCH ANGLE)  

C YY(7) = X-COMPONENT OF LINEAR VELOCITY  

C YY(8) = Y-COMPONENT OF LINEAR VELOCITY  

C YY(9) = Z-COMPONENT OF LINEAR VELOCITY  

C YY(10) = ANGULAR VELOCITY ABOUT X-AXIS (ROLL RATE)  

C YY(11) = ANGULAR VELOCITY ABOUT Y-AXIS (YAW RATE)  

C YY(12) = ANGULAR VELOCITY ABOUT Z-AXIS (PITCH RATE)  

C YY(13) = TIME INTEGRAL OF YAW ANGLE (EVALUATED ONLY  

C WHEN REQUIRED BY THE AUTOPILOT)  

C  

C YYDOT -- DERIVATIVES OF YY.  

C  

C TT AND YY ARE SUPPLIED TO THIS SUBROUTINE WHENEVER THE EQUATION  

C SOLVING ROUTINE REQUIRES THE VALUES OF THE DERIVATIVE OF YY--  

C YYDOT. YYDOT IS COMPUTED BY EVALUATING THE RIGHT HAND SIDE OF  

C THE EQUATIONS OF MOTION FOR THE GIVEN TT AND YY AND THE PRE-  

C DEFINED GEOMETRY OF THE SHIP AND EQUATIONS OF THE WAVES.  

C  

REAL YY(13), YYDOT(13)
COMMON /A/ A(6,6)
COMMON /C/ C(3,3)
COMMON /CT/ CT(3,3)
COMMON /FORCE/ XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1), XF)
COMMON /H/ H(3)
COMMON /MASS/ RHO, G, GAMMA
COMMON /MASS/ DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS/ PMI(3,3)
COMMON /STATS/ NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1
COMMON /TRIG/ CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /Z/ SCR(6)
COMMON/ACCEL/ACC(6)
NRHS(4)=NRHS(4)+1
IF (TT.GT.TT1) GO TO 90
IF (TT.EQ.TT1) GO TO 80
C *** Previous time step rejected
NRHS(3)=NRHS(3)+1
TTO=AMIN1(TT, TTO)
TT1=TTO
GO TO 100
C *** Previous time step repeated
80 NRHS(2)=NRHS(2)+1
GO TO 100
C
C *** Previous time step accepted
90 DELTA=TT1-TTO
TTO=TT1
TT1=TT

```

```

      IF (DELTA.LE.0.0) GO TO 100
      NRHS(1)=NRHS(1)+1
      HSUM=HSUM+DELTA
      HMIN=A MIN1(HMIN, DELTA)
      HMAX=A MAX1(HMAX, DELTA)
100   CONTINUE
C *** Compute forces on ship
      CALL FORTIS (TT, YY)
C *** Set the values of the derivatives
C *** Set up the H vector (angular momentum)
      H(1)=PMI(1,1)*YY(10)+PMI(1,2)*YY(11)+PMI(1,3)*YY(12)
      H(2)=PMI(2,1)*YY(10)+PMI(2,2)*YY(11)+PMI(2,3)*YY(12)
      H(3)=PMI(3,1)*YY(10)+PMI(3,2)*YY(11)+PMI(3,3)*YY(12)
C *** Set derivatives of position and rotation
      DO 110 I=1,3
         YYDOT(I)=YY(I+6)
110   CONTINUE
      YYDOT(5)=(YY(11)*CTHETA-YY(12)*STHETA)/CPSI
      YYDOT(4)=YY(10)-YYDOT(5)*SPSI
      YYDOT(6)=YY(11)*STHETA+YY(12)*CTHETA
C *** Solve for derivatives of linear and angular velocity
      YYDOT(7)=XF/SMASS
      YYDOT(8)=YF
      YYDOT(9)=ZF
      YYDOT(10)=XM-YY(11)*H(3)+YY(12)*H(2)
      YYDOT(11)=YM-YY(12)*H(1)+YY(10)*H(3)
      YYDOT(12)=ZM-YY(10)*H(2)+YY(11)*H(1)
      DET=0.0
      L=LNEG(6, 5, 1, A(2, 2), YYDOT(8), DET, SCR)
      IF (L.NE.1) STOP 1
C *** Load the acceleration array ACC [ship coordinates]
      ACC(1)=YYDOT(7)
      ACC(2)=YYDOT(8)
      ACC(3)=YYDOT(9)
      ACC(4)=YYDOT(10)
      ACC(5)=YYDOT(11)
      ACC(6)=YYDOT(12)
C
C *** Resolve linear accelerations into fixed coordinates.
      SCR(1)=YYDOT(7)
      SCR(2)=YYDOT(8)
      SCR(3)=YYDOT(9)
      YYDOT(7)=C(1,1)*SCR(1)+C(2,1)*SCR(2)+C(3,1)*SCR(3)
      YYDOT(8)=C(1,2)*SCR(1)+C(2,2)*SCR(2)+C(3,2)*SCR(3)
      YYDOT(9)=C(1,3)*SCR(1)+C(2,3)*SCR(2)+C(3,3)*SCR(3)
      YYDOT(13)=YY(5)
      RETURN
      END

```

SUBROUTINE ROTATE (YY)

C  
C1 SET UP COORDINATE ROTATION MATRICES CT AND C .  
C1 RESOLVE VELOCITY INTO SHIP COORDINATES.  
C1  
REAL YY(13)  
COMMON /C / C(3,3)  
COMMON /CT / CT(3,3)  
COMMON /TRIG / CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI  
COMMON /V / VX, VY, VZ  
CTHETA=COS(YY(4))  
STHETA=SIN(YY(4))  
CPHI=COS(YY(5))  
SPHI=SIN(YY(5))  
CPSI=COS(YY(6))  
SPSI=SIN(YY(6))  
C3  
C3 SET UP THE CT MATRIX..  
C3  
CT(1,1)=CPHI\*CPSI  
CT(1,2)=SPSI  
CT(1,3)=-SPHI\*CPSI  
CT(2,1)=-CPHI\*SPSI  
CT(2,2)=CPSI  
CT(2,3)=SPHI\*SPSI  
CT(3,1)=SPHI  
CT(3,2)=0  
CT(3,3)=CPHI  
C3  
C3 SET UP THE C MATRIX..  
C3  
C(1,1)=CT(1,1)  
C(1,2)=CT(1,2)  
C(1,3)=CT(1,3)  
C(2,1)=CTHETA\*CT(2,1)+STHETA\*CT(3,1)  
C(2,2)=CTHETA\*CT(2,2)  
C(2,3)=CTHETA\*CT(2,3)+STHETA\*CT(3,3)  
C(3,1)=CTHETA\*CT(3,1)-STHETA\*CT(2,1)  
C(3,2)=-STHETA\*CT(2,2)  
C(3,3)=CTHETA\*CT(3,3)-STHETA\*CT(2,3)  
C3  
C3 RESOLVE THE LINEAR VELOCITY INTO SHIP COORDINATES..  
C3  
VX=C(1,1)\*YY(7)+C(1,2)\*YY(8)+C(1,3)\*YY(9)  
VY=C(2,1)\*YY(7)+C(2,2)\*YY(8)+C(2,3)\*YY(9)  
VZ=C(3,1)\*YY(7)+C(3,2)\*YY(8)+C(3,3)\*YY(9)  
C3  
RETURN  
C  
END

## SUBROUTINE GETFREQ

```
C*****
C***** Evaluates frequency of accelerations of each
C***** strip in heave, sway and roll using recent
C***** history. The routine finds the last several
C***** peaks or troughs in the response history. Evaluates
C***** the time difference and calculates the frequency
C***** (rad/sec) and loads the OMEGAX( , ) array.
C*****
C5   WAVE PROPERTIES. .
COMMON /           / NWAVES, WVSUM,
1          WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          WN(20), WNX(20), WNZ(20),
3          CSK(20), CCK(20), CXK(20),
4          CYK(20), CZK(20), XW(20)
C5
C5   TABLE OF OFFSETS. .
COMMON /           / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1          XOFF(25), YOFF(25,25), ZOFF(25,25),
2          XPROF(51), YPROF(51)
* COMMON/ACCEL/ ACC(6)
* COMMON/SXGEOM/AREAS(25), DXS(25), DX1S(25), DX2S(25),
*          YMOMS(25), ZMOMS(25), ISTA, LSTA
* COMMON/SXOMEGL/OMEGAX(3)
* COMMON/HIST/AHIST(3,30), TIMTK(30)
* COMMON/TIME/TIME, RAMP
* COMMON/TIME/T0, TSTART, TSTOP, TOUTPT, TSTEP, ERR
* REAL TPK(10)
C-----
C----- SECTION 1.0 - Move values up one index in the AHIST
C----- array
C
      DO 100 J=30, 2, -1
      JM1=J-1
      AHIST(1, J)=AHIST(1, JM1)
      AHIST(2, J)=AHIST(2, JM1)
      AHIST(3, J)=AHIST(3, JM1)
100    CONTINUE
C
      DO 110 I=30, 2, -1
      IM=I-1
      TIMTK(I)=TIMTK(IM)
110    CONTINUE
C----- SECTION 2.0 - Calculate acceleration of a strip J in
C----- heave, sway and roll using the ACC(I)
C----- array giving ship accelerations in ship
C----- coordinate system.
C
      XDUM=10. !Arbitrary moment arm to get better
C           defined history
      AH=ACC(2)+ACC(6)*XDUM
      AS=ACC(3)-ACC(5)*XDUM
```

```

C      AR=ACC(4)
C
C      AHIST(1, 1)=AH
C      AHIST(2, 1)=AS
C      AHIST(3, 1)=AR
C
200  CONTINUE
C
C      TIMTK(1)=TIME
C
C      IF(TIME.LE.RAMP) GO TO 400
C
C-----C
C      SECTION 3.0 - Find peaks and troughs, evaluate freq.
C      [Note: Here we are evaluating frequency
C      using only the last quarter of a "cycle".
C      If we wanted to use a half cycle, we
C      would get out of the GOTO310 loop when
C      KNT=3 instead of KNT=2 and change
C      the 'TQ='... line to
C      TQ=TPK(3)-TPK(1) followed by
C      OMEGAX(I)=2.*PI/(2.*TQ)
C
C-----C
C
DO 300 I=1,3
L=0
KNT=0
TSIGN=1
310  CONTINUE
L=L+1
IF(L.EQ.30) GO TO 325
TSIGN2=TSIGN
DIF=AHIST(I,L)-AHIST(I,L+1)
TSIGN=SIGN(1.,DIF)
IF(L.EQ.1) GO TO 310
IF(TSIGN2.EQ.TSIGN) GO TO 310
KNT=KNT+1
TPK(KNT)=TIMTK(L)
IF(KNT.EQ.2) GO TO 320
GO TO 310
C
320  CONTINUE
TQ=TPK(1)-TPK(2)
OMEGAX(I)=6.2831853/(4.*TQ)
GO TO 300
325  OMEGAX(I)=0.
C
300  CONTINUE
C
400  CONTINUE
RETURN
END

```

```

CCC      SUBROUTINE OUTCOF
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON/MASS/RHO, G, GAMMA
COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,
*           AMX, AMY, AMZ, RADII(6)
COMMON/LHS/Y(13)
COMMON /           NWAVES, WVSUM,
1          WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          WN(20), WNX(20), WNZ(20),
3          CSK(20), CCK(20), CXK(20),
4          CYK(20), CZK(20), XW(20)
COMMON /           MSTA, NPROF, NFWD, NAFT, LPTS(25),
1          XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2          XPROF(51), YPROF(51)
COMMON/RESIST/SPEED
COMMON/SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)

C
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)
COMMON/COEFFX/THAH(25, 21), TSAS(25, 21), TRAR(25, 21), TCCA(25, 21),
*           THVH(25, 21), TSVS(25, 21), TRVR(25, 21), TCCV(25, 21),
*           THACX(25, 21), THVCX(25, 21), TSACX(25, 21), TSVCX(25, 21),
*           TRACX(25, 21), TCACX(25, 21), THVCY(25, 21),
*           ITP(25), TXP(25), IPP(21), FXP(21)
COMMON/OPTION/JOBCO, JOBF0(10)
COMMON/SXOMEG/OMEGAX(3)
COMMON/DRFT1/ DRAFT1(6)

C       DATA DEGREE/0. 01745 32925/
C-----
C       WRITE(OUTPUT, 2)
C       WRITE(OUTPUT, 3)
DO 10 J=1, MSTA
WRITE(OUTPUT, 1) J, THAH(J, 21), TSAS(J, 21), TRAR(J, 21), TCCA(J, 21)
CONTINUE
10
C       WRITE(OUTPUT, 4)
DO 20 J=1, MSTA
WRITE(OUTPUT, 1) J, THVH(J, 21), TSVS(J, 21), TRVR(J, 21), TCCV(J, 21)
CONTINUE
20
C       WRITE(OUTPUT, 5)
DO 30 J=1, MSTA
WRITE(OUTPUT, 1) J, THACX(J, 21), TSACX(J, 21), THVCX(J, 21),
*           TSVCX(J, 21)
CONTINUE
30
C       DO 40 K=1, NWAVES
WRITE(OUTPUT, 6) K
WRITE(OUTPUT, 3)
DO 110 J=1, MSTA
WRITE(OUTPUT, 1) J, THAH(J, K), TSAS(J, K), TRAR(J, K), TCCA(J, K)
CONTINUE
110
C       WRITE(OUTPUT, 4)
DO 120 J=1, MSTA
WRITE(OUTPUT, 1) J, THVH(J, K), TSVS(J, K), TRVR(J, K), TCCV(J, K)

```

```
120    CONTINUE
C
WRITE(OUTPUT,5)
DO 130 J=1,MSTA
WRITE(OUTPUT,1) J, THACX(J,K), TSACX(J,K), THVCX(J,K), TSVCX(J,K)
130    CONTINUE
40    CONTINUE
1    FORMAT(1X, I2, 5X, 4E15. 5)
2    FORMAT(/'*****TEMPORARY HYDRODYNAMIC COEFFICIENTS*****'//)
3    FORMAT(1X, 'STA', 4X, 'HAH', 12X, 'SAS', 12X, 'RAR', 12X, 'CCA')
4    FORMAT(1X, 'STA', 4X, 'HVH', 12X, 'SVS', 12X, 'RVR', 12X, 'CCV')
5    FORMAT(1X, 'STA', 4X, 'HACX', 11X, 'SACX', 11X, 'HVCX', 11X, 'SVCX', /)
6    FORMAT(/1X, 'WAVE NO. - ', I2/)
RETURN
END
```

```

SUBROUTINE FOLIO2
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
COMMON /LHS   /      Y(13)
COMMON /TIME  /      TIME, RAMP
COMMON /TIME  /      TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON /      /      NWAVES, WVSUM,
1          WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          WN(20), WNX(20), WNZ(20),
3          CSK(20), CCK(20), CXK(20),
4          CYK(20), CZK(20), XW(20)
COMMON/SUMMARY/ NT, YYBAR(10), YYRMS(10), YYMAX(10), YYMIN(10)
COMMON/LOADS/ SIN2(25), SIN3(25), SIN4(25), SINS(25), SIN6(25),
1          V2(25), V3(25), V4(25), V5(25), V6(25),
2          RED(6,25)
COMMON/DISPLAY/TARE(10)
REAL YS(10)
EQUIVALENCE (ETA, YS(1))
DATA RAD /0.01745 32925 19943/
ETA=0.0
IF (NWAVES.EQ.0) GO TO 120
C *** Wave amplitude @ c. g.
DO 110 K=1,NWAVES
  ARG=Y(1)*WNX(K)-Y(3)*WNZ(K)-TIME*WVFRE(K)+WVPHA(K)
  ETA=COS(ARG)*WVAMP(K)+ETA
110 CONTINUE
C *** Position vector
120 DO 130 I=1,3
  YS(I+1)=Y(I)
  YS(I+4)=Y(I+3)/RAD
130 CONTINUE
C *** Display relative heave -- subtract c.g. height
C above baseline to bring mean value to zero.
YS(3)=YS(3)-TARE(2)
C *** Speed and sway rate
CPHI=COS(Y(5))
SPHI=SIN(Y(5))
YS(8)=0.
YS(8)=V6(14) !NO RUDDER BENDING MOMENT AT STATION J=14
YS(9)=Y(7)*CPHI - Y(9)*SPHI
YS(10)=Y(9)*CPHI+ Y(7)*SPHI
C *** Load mean and rms information
TINIT=.75*TSTOP
IF(TIME.LE.TINIT) GO TO 199
NT=NT+1
IF(NT.NE.1) GO TO 198
DO 184 I=1,10
YYMAX(I)=0.0
YYMIN(I)=0.0
YYBAR(I)=0.
YYRMS(I)=0.
184 CONTINUE
C
198 CONTINUE
C
DO 185 I=1,10
IF(YS(I).GT.YYMAX(I)) YYMAX(I)=YS(I)
IF(YS(I).LT.YYMIN(I)) YYMIN(I)=YS(I)
C
YYBAR(I)=YYBAR(I)+YS(I)
YYRMS(I)=YYRMS(I)+YS(I)**2

185 CONTINUE
C
199 CONTINUE
C *** Write to history file
WRITE(10) YS(1),YS(3),YS(7),YS(5),YS(6),YS(4)
C *** Print YS vector
WRITE (OUTPUT,190) TIME, (YS(I), I=1,9)
C
RETURN
C
190 FORMAT(5(1X,F11.4),3F12.4,2X,E15.5,2X,F12.4)
END

```

```

SUBROUTINE FORTIS (TT, YY)
  TT -- TIME, THE INDEPENDENT VARIABLE
  YY -- DEPENDENT VARIABLE ARRAY.
    YY(1) = X-COORDINATE OF MASS CENTER
    YY(2) = Y-COORDINATE OF MASS CENTER
    YY(3) = Z-COORDINATE OF MASS CENTER
    YY(4) = THETA ROTATION (ROLL ANGLE)
    YY(5) = PHI ROTATION (YAW ANGLE)
    YY(6) = PSI ROTATION (PITCH ANGLE)
    YY(7) = X-COMPONENT OF LINEAR VELOCITY
    YY(8) = Y-COMPONENT OF LINEAR VELOCITY
    YY(9) = Z-COMPONENT OF LINEAR VELOCITY
    YY(10) = ANGULAR VELOCITY ABOUT X-AXIS (ROLL RATE)
    YY(11) = ANGULAR VELOCITY ABOUT Y-AXIS (YAW RATE)
    YY(12) = ANGULAR VELOCITY ABOUT Z-AXIS (PITCH RATE)

REAL YY(12)
COMMON /C/ C(3,3)
COMMON /DAMP/ DAMPL(6), DAMPQ(6)
COMMON /FORCE/ XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1), XF)
COMMON /MASS/ RHO, G, GAMMA
COMMON /MASS/ DISPL, SMASS, XCG, YCG, ZCG,
1 AMX, AMY, AMZ, RADII(6)
COMMON /MASS/ PMI(3,3)
COMMON /STATS/ NRHS(4), DELTA, HSUM, HMIN, HMAX, TTO, TT1
COMMON /TIME/ TIME, RAMP
COMMON /TIME/ TO, TSTART, TSTOP, TOUTPT, TSTEP, ERR
COMMON /TRIG/ CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /V/ VX, VY, VZ
C *** Load rotational transform matrices - transform velocity
C into ship coordinates
CALL ROTATE (YY)
C *** Initialize force vector
DO 110 I=1,6
  FORCE(I)=0.0
110 CONTINUE
C
C *** Ensure constant speed for version SSX
VX=SPEED
C *** Compute hydrodynamic and inertial forces on ship
CALL AQUA2D (TT, YY)
C *** Add damping forces/moments in ship coordinate system
XF=XF-(DAMPL(1)+ABS(VX)*DAMPQ(1))*VX
YF=YF-(DAMPL(2)+ABS(VY)*DAMPQ(2))*VY
ZF=ZF-(DAMPL(3)+ABS(VZ)*DAMPQ(3))*VZ
XM=XM-(DAMPL(4)+ABS(YY(10))*DAMPQ(4))*YY(10)
YM=YM-(DAMPL(5)+ABS(YY(11))*DAMPQ(5))*YY(11)
ZM=ZM-(DAMPL(6)+ABS(YY(12))*DAMPQ(6))*YY(12)
C *** Fixed added mass coefficients - not normally used except
C perhaps for surge.
XF=XF/AMX
YF=YF/AMY
ZF=ZF/AMZ
C
C *** Ramp function applied to force
IF (TT.GT.TSTART) GO TO 130
IF (RAMP.EQ.0.0) GO TO 130
R=(TT-TO)/RAMP

DO 120 I=1,6
  FORCE(I)=FORCE(I)*R
120 CONTINUE
130 CONTINUE
C
RETURN
END

```

```

SUBROUTINE SPECTRA(PFRQ, TRWH13, OMGBEG, OMGEND, WAMP, PER)
DIMENSION WAMP(10), PER(10), OMEGA(10)
DIMENSION OMG2(101), SPEC(101)
IC1=-8
IC2=0
IC3=-7
IC4=-1
IC5=-9
IC6=1
IW=0
OMG2(1)=OMGBEG
OMG2(101)=OMGEND
1 DELFRQ=(OMG2(101)-OMG2(1))/101.
DO 5 I=2, 101
J=I-1
5 OMG2(I)=OMG2(1)+J*DELFRQ
DO 6 I=1, 101
6 OMG2(I)=OMG2(I)/(2.*3.14159)
DO 7 I=1, 101
7 SPEC(I)=5.*(.25*TRWH13)**2*PFRQ*(OMG2(I)*PFRQ)**(-5)*EXP(
10 (-5./4.)*(OMG2(I)*PFRQ)**(-4))
ODD=0.
EVEN=0.
20 DO 20 . , 50, 2
EVEN=EVEN+SPEC(I)
DO 30 I=3, 99, 2
30 DDD=DDD+SPEC(I)
TAREA=(OMG2(2)-OMG2(1))/3.* (SPEC(1)+4.*EVEN+2.*ODD+SPEC(101))
40 IC1=IC1+10
IC2=IC2+10
IC3=IC3+10
IC4=IC4+10
IC5=IC5+10
IC6=IC6+10
ODD=0.
EVEN=0.
IW=IW+1
50 DO 50 I=IC1, IC2, 2
EVEN=EVEN+SPEC(I)
DO 60 I=IC3, IC4, 2
60 DDD=DDD+SPEC(I)
WAMP(IW)=(OMG2(2)-OMG2(1))/3.* (SPEC(IC5)+4.*EVEN+2.*ODD+SPEC(IC6))
1 WAMP(IW)=1.414*SQRT(WAMP(IW))
PER(IW)=(OMG2(IC6)+OMG2(IC5))/2.
OMEGA(IW)=2.*3.14159*PER(IW)
PER(IW)=1./PER(IW)
IF(IW.LT.10) GO TO 40
PRINT 500, TRWH13, PFRQ, OMEGA, PER, WAMP
RMS=4.*SQRT(TAREA)
PRINT 1010, TAREA, RMS
500 FORMAT(15X, 'H1/3=', F10.2, 2X, 'PEAK FREQ=', F10.4, //, 2X,
1 'OMG', 3X, 10F6.3, //, 2X, 'PER', 3X, 10F6.2, //, 2X, 'WAMP', 2X,
2 10F6.2)
1010 FORMAT(2X, 'TOTAL AREA=', F10.2, 5X, 'RMS=', F10.2)
RETURN
END
SUBROUTINE LINEAR(X, Y, TRWPY, Y2)
DIMENSION X(50), Y(50), Y2(10)
DIMENSION TRWPY(10)
J=0

```

```
140      RA=SQRT((X-XF)**2+(Y-YF)**2+(Z-ZF)**2)
        FRA=ARM/RA
1380     RB=SQRT((X-XF)**2+(Y-YF)**2+(Z+ZF)**2)
        FRA=FRA-ARM/RB
        FRX=-AN(MJ, 1)*FRA
        FRY=-AN(MJ, 2)*FRA
        FRZ=-AN(MJ, 3)*FRA
        P1=P1+FRX
        P2=P2+FRY
        P3=P3+FRZ
        P4=P4+YF*FRZ-ZF*FRY
        P5=P5+ZF*FRX-XF*FRZ
        P6=P6+XF*FRY-YF*FRX
        PBB(NJ, MJ)=PBB(NJ, MJ)+FRA*ARN
138      CONTINUE
        P(NJ, 1)=P(NJ, 1)+P1*ARN
        P(NJ, 2)=P(NJ, 2)+P2*ARN
        P(NJ, 3)=P(NJ, 3)+P3*ARN
        P(NJ, 4)=P(NJ, 4)+P4*ARN
        P(NJ, 5)=P(NJ, 5)+P5*ARN
        P(NJ, 6)=P(NJ, 6)+P6*ARN
128      CONTINUE
127      CONTINUE
      DO 554 KQ=1, 6
554      WRITE(3) (P(NJ, KQ), NJ=1, NPAN)
      RETURN
      END
```

```
TOPI=2.*3.14159
DO 20 II=1,10
IF(II.GT.1) GO TO 69
50   J=J+1
69   IF(TOPI/TRWPER(II)-X(J))112,111,110
110  GOTO 50
111  Y2(II)=Y(J)
112  GOTO 20
      1 Y2(II)=Y(J-1)+(Y(J)-Y(J-1))/(X(J)-X(J-1))*  

      (TOPI/TRWPER(II)-X(J-1))
20    CONTINUE
      RETURN
      END
```

```

CCC      SUBROUTINE TBAR(TT, YY)
CCC      EXTERNAL ETAF
CCC
COMMON/MASS/RHO, G, GAMMA
COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,
*          AMX, AMY, AMZ, RADII(6)
COMMON /           / NWAVES, WVSUM,
1          WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          WN(20), WNX(20), WNZ(20),
3          CSK(20), CCK(20), CXK(20),
4          CYK(20), CZK(20), XW(20)
COMMON /           / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1          XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2          XPROF(51), YPROF(51)
COMMON/ETA/YC, XK(20)
COMMON/CT/CT(3, 3)
COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)
COMMON/DISPLAY/TARE(6)
REAL YY(1)

C          DATA DEGREE/0.01745 32925/
C          SECTION 1.0    Compute average draft at each station
C                      TSTA(J).

C          DO 2 K=1, NWAVES
C          CXK(K)=CT(1, 1)*WNX(K)-CT(1, 3)*WN(K)
C          XW(K)=(TT*WVFRE(K)-WVPHA(K)+YY(3)*WNZ(K)-YY(1)*WNX(K))/CXK(K)
2        CONTINUE

C          DO 5 J=1, MSTA
C          XXSTA=XOFF(J)
C          IF(NWAVES, EQ, 0) GO TO 11
C          DO 10 K=1, NWAVES
C          XK(K)=(XXSTA-XW(K))*CXK(K)
10        CONTINUE
C          YC=CT(1, 2)*XXSTA+YY(2)
C          YKEEL=YCG-TARE(2)-YC
C          ETA1=ETAF(0, )
C          TSTA(J)=ETA1-YKEEL
C          CONTINUE
5        CONTINUE

C          RETURN
CCC          END

```

SUBROUTINE MOCHA

CCC  
CCC  
CCC  
CCC  
CCC

Purpose: For JOBCO=2,3 or 4 . . . this subroutine  
will load the COMMON/COEFFX/ arrays for use in  
subroutine FROUDE.

COMMON/MASS/RHO, G, GAMMA  
COMMON/MASS/DISPL, SMASS, XCG, YCG, ZCG,  
\* AMX, AMY, AMZ, RADII(6)  
\* COMMON/LHS/Y(13)  
C5 WAVE PROPERTIES. . .  
COMMON / / NWAVES, WVSUM,  
1 WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),  
2 WN(20), WNX(20), WNZ(20),  
3 CSK(20), CCK(20), CXK(20),  
4 CYK(20), CZK(20), XW(20)  
C5  
C5  
C5 TABLE OF OFFSETS. . .  
COMMON / / MSTA, NPROF, NFWD, NAFT, LPTS(25),  
1 XOFF(25), YOFF(25,25), ZOFF(25,25),  
2 XPROF(51), YPROF(51)  
COMMON/RESIST/SPEED  
COMMON/SIGMA / NK,SIGMA(24),SIGMA0, ERRO, OM(12)  
C  
COMMON/COEFF4/COEFF4(6, 12, 8, 25), AREAN(25, 6)  
COMMON/COEFFX/THAH(25, 21), TSAS(25, 21), TRAR(25, 21), TCCA(25, 21),  
\* THVH(25, 21), TSVS(25, 21), TRVR(25, 21), TCCV(25, 21),  
\* THACX(25, 21), THVCX(25, 21), TSACX(25, 21), TSVCX(25, 21),  
\* TRACX(25, 21), TCACX(25, 21), THVCY(25, 21),  
\* ITP(25), TXP(25), IFP(21), FXP(21)  
COMMON/OPTION/JOBCO, JOBF0(10)  
COMMON/ETA/YC, XK(20)  
COMMON/CT/CT(3, 3)  
COMMON/SXOMEG/OMEGAX(3)  
COMMON/DRFT1/ DRAFT1(6)  
COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)  
C  
DATA DEGREE/0. 01745 32925/  
C SECTION 1.0 Compute average draft at each station  
TSTA(J).  
C  
C No longer required here. Now done in FROUDE right  
C before the call to MOCHA  
C  
C SECTION 2.0 Computations for Coefficients used  
C in Wave Exciting/Diffraction Force  
C Calculations  
C  
DO 10 J=1,MSTA  
DO 10 K=1,NWAVES  
C  
IF (JOBCO.EQ.2. OR. JOBCO.EQ.4) THEN  
  IF=IFP(K)  
  FX=FXP(K)  
  CALL TXIT(TSTA(J), IT, TX)  
ELSE IF (JOBCO.EQ.3) THEN  
  IT=ITP(J)

```

      TX=TXP(J)
      IF=IFP(K)
      FX=FXP(K)
END IF

C
      THAH(J,K)=COX(IT,TX,IF,FX,1,J)
      TSAS(J,K)=COX(IT,TX,IF,FX,2,J)
      TRAR(J,K)=COX(IT,TX,IF,FX,3,J)
      TCCA(J,K)=COX(IT,TX,IF,FX,4,J)

C
      THVH(J,K)=COX(IT,TX,IF,FX,5,J)
      TSVS(J,K)=COX(IT,TX,IF,FX,6,J)
      TRVR(J,K)=COX(IT,TX,IF,FX,7,J)
      TCCV(J,K)=COX(IT,TX,IF,FX,8,J)

C
C Spatial derivatives in x-direction
C
      THACX(J,K)=CODXDX(IT,TX,IF,FX,1,J)
      TSACX(J,K)=CODXDX(IT,TX,IF,FX,2,J)
      TRACX(J,K)=CODXDX(IT,TX,IF,FX,3,J)
      TCACX(J,K)=CODXDX(IT,TX,IF,FX,4,J)

C
      10 CONTINUE

CCC
      SECTION 3.0 - This section computes coefficients
      for ship motion related force
      computations, using OMEGAX( ) as
      the frequency at which computations
      are performed. OMEGAX(1) - HEAVE,
      OMEGAX(2) - SWAY, OMEGAX(3) - ROLL.
      These are computed in Subroutine
      GETFREQ.

DO 20 J=1,MSTA
C
      IF(JOBC0.EQ.2) THEN
          IF=IFP(21)
          FX=FXP(21)
          IFH=IF
          IFS=IF
          IFR=IF
          FXH=FX
          FXS=FX
          FXR=FX
          CALL TXIT(TSTA(J),IT,TX)
      ELSE IF(JOBC0.EQ.3) THEN
          IT=ITP(J)
          TX=TXP(J)
          CALL FXIF(OMEGAX(1),IFH,FXH)
          CALL FXIF(OMEGAX(2),IFS,FXS)
          CALL FXIF(OMEGAX(3),IFR,FXR)
      ELSE IF(JOBC0.EQ.4) THEN
          CALL TXIT(TSTA(J),IT,TX)
          CALL FXIF(OMEGAX(1),IFH,FXH)
          CALL FXIF(OMEGAX(2),IFS,FXS)
          CALL FXIF(OMEGAX(3),IFR,FXR)
C
      END IF

```

THAH(J, 21)=COX(IT, TX, IFH, FXH, 1, J)  
TSAS(J, 21)=COX(IT, TX, IFS, FXS, 2, J)  
TRAR(J, 21)=COX(IT, TX, IFR, FXR, 3, J)  
TCCA(J, 21)=COX(IT, TX, IFS, FXS, 4, J)

C

THVH(J, 21)=COX(IT, TX, IFH, FXH, 5, J)  
TSVS(J, 21)=COX(IT, TX, IFS, FXS, 6, J)  
TRVR(J, 21)=COX(IT, TX, IFR, FXR, 7, J)  
TCCV(J, 21)=COX(IT, TX, IFS, FXS, 8, J)

C

Spatial Derivatives in x-direction

C

THACX(J, 21)=COXDX(IT, TX, IFH, FXH, 1, J)  
TSACX(J, 21)=COXDX(IT, TX, IFS, FXS, 2, J)  
THVCX(J, 21)=COXDX(IT, TX, IFH, FXH, 5, J)  
TSVCX(J, 21)=COXDX(IT, TX, IFS, FXS, 6, J)

C

20 CONTINUE

C

[Note: Vertical derivative of added mass computed  
in SUBROUTINE FROUDE or COFFEE.]

C

RETURN  
END

C

SUBROUTINE AQUA2D (TT, YY)

C----  
C CALCULATES SHIP-MOTION INDUCED FORCES, WAVE INDUCED FORCES,  
C AND OTHER HYDRODYNAMIC FORCES ON THE SHIP.

SECTION	DESCRIPTION
1. 0	INITIALIZATION
2. 0	FIND WET OFFSET POINTS/ENDS OF HULL
3. 0	INITIALIZATION
4. 0	CALCULATE VARIOUS 2-D INTEGRALS/GEOMETRIC INFO. FC
5. 0	CALCULATE FORCES THAT ARE SHIP-MOTION RELATED
6. 0	CALCULATE DORCES THAT ARE WAVE-INDUCED
7. 0	CALCULATE OTHER FORCES
8. 0	INTEGRATE FORCES OVER LENGTH
9. 0	ADD UP FORCES AND LOAD FORCE ARRAY
10. 0	LOAD MASS/INERTIA MATRIX A(I,J)

C----

C NOTE: The hydrodynamic coefficients were divided by sectional area in  
C COEFS part of this program. They were also divided by RHO in t  
C subroutine. Thus, quantities are multiplied by DVOL  
C when they would normally be multiplied by DX, and there  
C are several places where a coefficient is divided by G operate  
C to make sure that all the units are consistent from force to  
C force. At any point in the force calculations, one must  
C multiply by GAMMA to obtain force in lbs.

C----

C1

```
REAL YY(1)
COMMON /A      /  A(6,6)
COMMON /AM     /  YFYA, ZFZA, XMZA, XMXR, XMYR,
1   YMZA, YMYR, ZMYA, ZMZR
COMMON/RESIST/SPEED
REAL VT(6), AM(9)
EQUIVALENCE (AM(1), YFYA)
COMMON /C      /  C(3,3)
COMMON /CT     /  CT(3,3)
COMMON /ETA    /  YC, XK(20)
COMMON /FORCE  /  XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1), XF)
COMMON /MASS   /  RHO, G, GAMMA
COMMON /MASS   /  DISPL, SMASS, XCG, YCG, ZCG,
1   AMX, AMY, AMZ, RADII(6)
COMMON /MASS   /  PMI(3,3)
COMMON /TRIG   /  CTHETA, STHETA, CPHI, SPHI, CPSI, SPSI
COMMON /V      /  VX, VY, VZ
COMMON /        /  NWAVES, WVSUM,
1   WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2   WN(20), WNX(20), WNZ(20),
3   CSK(20), CCK(20), CXK(20),
4   CYK(20), CZK(20), XW(20)
COMMON /        /  MSTA, NPROF, NFWD, NAFT, LPTS(25),
1   XOFF(25), YOFF(25,25), ZOFF(25,25),
2   XPROF(51), YPROF(51)
COMMON /        /  INPTS(25), IPOINT(25), YWET(25,25), ETA(25,25),
1   ZLAST(25,25), ZWET(25,25), ZNEXT(25,25)
```

```

1 COMMON /           / ZCO(20), ZSO(20), ZCY(20), ZSY(20),
1 COMMON /           / ZCZ(20), ZSZ(20)
1 COMMON /           / DZK(20)
1 COMMON /           / JSAVE(20), COSJ(20), SINJ(20),
$           COSJJ(20), SINJJ(20),
1           DWC(20), DWS(20), XCI(20), XSI(20)
1 COMMON /AREA   / AREA, YMOM, ZMOM
EQUIVALENCE (FWD, XPROF(51)), (AFT, YPROF(51))
COMMON/SXFOR/ FBUDY(6,25), FDAMP(6,25), FADMA(6,25), FWVEX(6,25),
*           UDAMP(6,25), UADMA(6,25), UWVEX(6,25), FFLAR(6,25)
* COMMON/SXGEOM/AREAS(25), DXS(25), DX1S(25), DX2S(25),
*           YMOMS(25), ZMOMS(25), ISTA,LSTA
COMMON/SXDOMEQ/DMEGAX(3)
COMMON/TEMPSTA/DXFWD, DXAFT, TSTA(25)
COMMON/OPTION/JOBCO, JOBFO(10)
DIMENSION COLD(25), CNEW(25), TOLD(25), TNEW(25)
DIMENSION TTOLD(25), TTNEW(25)
REAL ZEROF(1200)
EQUIVALENCE (ZEROF(1), FBUDY(1,1))
COMMON/FCOMP/XFB, YFB, ZFB, XMB, YMB, ZMB,
1           XFD, YFD, ZFD, XMD, YMD, ZMD,
2           XFX, YFX, ZFX, XMX, YMX, ZMX,
3           XFN, YFN, ZFN, XMN, YMN, ZMN,
4           XFU, YFU, ZFU, XMU, YMU, ZMU,
5           YFF, ZMF
REAL ZEROC(32)
EQUIVALENCE (ZEROC(1), XFB)
COMMON/CoeffFX/THAH(25,21), TSAS(25,21), TRAR(25,21), TCCA(25,21),
*           THVH(25,21), TSVS(25,21), TRVR(25,21), TCCV(25,21),
*           THACX(25,21), THVCX(25,21), TSACX(25,21), TSVCX(25,21),
*           TRACX(25,21), TCACX(25,21), THVCY(25,21),
*           ITP(25), TXP(25), IFP(21), FXP(21)
C *** Initialization
C     IF (NWAVES.EQ.0) GO TO 120
C-----
C----- SECTION 1.0 - INITIALIZATION
C----- Project wave numbers into calculation coordinate system
C----- (yaw and pitch but not roll). Compute x-coord of wave
C----- crest.
C----- DO 110 K=1,NWAVES
      CSK(K)=CT(1,2)*WN(K)
      CCK(K)=CT(2,2)*WN(K)
      CXK(K)=CT(1,1)*WNX(K)-CT(1,3)*WNZ(K)
      CYK(K)=CT(2,1)*WNX(K)-CT(2,3)*WNZ(K)
      CZK(K)=CT(3,1)*WNX(K)-CT(3,3)*WNZ(K)
      DZK(K)=2.0/CZK(K)
      XW(K)=(TT*WVFRE(K)-WVPHA(K)+YY(3)*WNZ(K)-YY(1)*WNX(K))/CXK(K)
      JSAVE(K)=0
110 CONTINUE
120 CONTINUE
C4
C----- 1.1 Zero the acceleration force coefficients AM(I) and
C----- zero the sectional force arrays in common SXFOR.
C----- C4

```

```

        DO 130 I=1,9
        AM(I)=0.0
130 CONTINUE
C*
        DO 131 I=1,1200
        ZEROF(I)=0.0 ! Equivalenced with COMMON/SXFOR/
131 CONTINUE
C*
C       DO 800 I = 1,32
        ZEROC(I)=0. !ZEROC is EQUIVALENCED with COMMON/FCOMP/
800 CONTINUE
C
C*
C-----  

C       1.2 Load COMMON/COEFFX/ if JOBCO=2,3 or 4
C-----  

C
C       CALL TBAR(TT,YY)      !Get average draft at every sta.
C       TYPE 1000, (TSTA(J),J=1,MSTA)
1000 FORMAT(1X,25F5.1)
C       DO 1000 J=1,MSTA
C       TSTA(J)=32.8
C1000 CONTINUE
C
C       IF(JOBCO.NE.1.AND.TT.GT.0.) CALL MOCHA
C
C       ISTA=0
C-----  

C
C       SECTION 2.0 - FIND WET OFFSET POINTS AND HULL ENDS
C-----  

C
C3
C3       FIND WET OFFSET POINTS.
C3
C3       ETA(L)    = Y-COORDINATE OF WAVE SURFACE,
C3       YWET(L)   = Y-COORDINATE OF WET OFFSET POINT.
C3       ZWET(L)   = Z-COORDINATE OF WET OFFSET POINT.
C3       ZLAST(L)  = Z-COORDINATE OF EITHER THE PREVIOUS WET OFFSET
C3                  POINT OR THE Z-COORDINATE OF THE WATER SURFACE,
C3       ZNEXT(L)  = Z-COORDINATE OF EITHER THE NEXT WET OFFSET POINT
C3                  OR THE Z-COORDINATE OF THE WATER SURFACE.
C3
C4
C4       KEY INDICATES THE STATUS OF THE SEARCH:
C4
C4       KEY = 1 -- THE FIRST OFFSET POINT IS BEING TESTED,
C4       KEY = 2 -- THE LAST OFFSET POINT WAS WET,
C4       KEY = 3 -- THE LAST OFFSET POINT WAS DRY (ETA COMPUTED),
C4       KEY = 4 -- THE LAST OFFSET POINT WAS DRY AND ETAMAX WAS
C4                  USED (ETA WAS NOT COMPUTED).
C4
C-----  

C
C       DO 260 J=1,MSTA
        KEY=1

```

```

I=1
L=0
LWET=0
N=LPTS(J)
XXSTA=XOFF(J)
IF (NWAVES.EQ.0) GO TO 150
DO 140 K=1,NWAVES
  XK(K)=(XXSTA-XW(K))*CXK(K)
140 CONTINUE
150 YC=CT(1,2)*XXSTA+YY(2)
ETAMAX=(WVSUM-YC)/CT(2,2)
160 Y1=YOFF(I,J)*CTHETA-ZOFF(I,J)*STHETA
Z1=ZOFF(I,J)*CTHETA+YOFF(I,J)*STHETA
IF (KEY.LT.3) GO TO 170
C5 THE PREVIOUS OFFSET POINT WAS DRY. AN ESTIMATE OF ETA WILL BE
C5 USED TO SEE IF THIS POINT CAN BE WET.
C5
C5 IF (Y1.LT.ETAMAX) GO TO 170
KEY=4
GO TO 230
C4 COMPUTE THE Y-COORDINATE OF THE WATER SURFACE..
C4
C4 170 ETA1=ETAF(Z1)
IF (KEY.GT.1) GO TO 180
C5 SAVE INITIAL CALCULATIONS FOR USE WITH FINAL OFFSET POINT.
C5 THE INITIAL AND FINAL OFFSETS REFER TO THE SAME POINT.
C5
EFIRST=ETA1
YFIRST=Y1
YO=Y1
ZFIRST=Z1
ZO=Z1
C4 TEST THE POSITION OF THE CURRENT OFFSET POINT RELATIVE TO THE
C4 WATER SURFACE. THE IF TEST IS SATISFIED IF THE POINT IS
C4 BELOW THE WATER SURFACE.
C4
180 IF (Y1.LT.ETA1) GO TO (212,210,200,190),KEY
C5 THE CURRENT OFFSET POINT IS DRY. IF KEY=2, THE PREVIOUS POINT
C5 WAS WET, AND THE Z-COORDINATE OF THE INTERSECTION OF THE HULL
C5 AND THE WATER SURFACE MUST BE FOUND BY INTERPOLATION.
C5
IF (KEY.NE.2) GO TO 181
ZNEXT(L,J)=(Z1-Z0)/(Y1-ETA1+EY)*EY+ZO
LWET=L
181 KEY=3
GO TO 220
C5 IF KEY = 4, THE ETA VALUE FOR THE LAST OFFSET POINT WAS NOT
C5 COMPUTED. COMPUTE ETA..
C5
190 EY=ETAF(Z0)-YO
C5 THE CURRENT OFFSET POINT IS WET, AND THE PREVIOUS POINT IS DRY.
C5 INTERPOLATE TO FIND THE INTERSECTION OF THE HULL AND THE WATER
C5 SURFACE..
C5

```

```

200      ZO=ZO+(Z1-ZO)/(Y1-ETA1+EY)*EY
        GO TO 211
C4      A WET OFFSET POINT HAS BEEN LOCATED.  STORE THE REQUIRED
C4      COORDINATE VALUES. .
C4
210      ZNEXT(L, J)=Z1
211      IF (I.EQ.N) GO TO 240
212      L=L+1
        ETA(L, J)=ETA1
        YWET(L, J)=Y1
        ZWET(L, J)=Z1
        ZLAST(L, J)=ZO
        KEY=2
C5      SAVE THE COMPUTED COORDINATE OF THE WATER SURFACE. .
C5
220      EY=ETA1-Y1
C5      SAVE THE COORDINATES OF THE OFFSET POINT. .
C5
230      YO=Y1
        ZO=Z1
C4      INCREMENT THE INDEX OF THE OFFSET POINT FOR THIS STATION. IF
C4      THE INDEX DOES NOT REFER TO THE LAST POINT, REPEAT THE LOOP.
C4
        I=I+1
        IF (I.LT.N) GO TO 160
        IF (I.GT.N) GO TO 250
C5      FOR THE LAST OFFSET POINT, THE VALUES OF ETA1, X1, AND Y1 ARE
C5      THE SAME AS FOR THE FIRST OFFSET POINT. REPEAT THE LOOP USING
C5      THESE VALUES. .
C5
        ETA1=EFIRST
        Y1=YFIRST
        Z1=ZFIRST
        GO TO 180
C4      A COMPLETE SEARCH OVER ALL THE OFFSET POINTS FOR THE CURRENT
C4      STATION HAS OBTAINED L WET OFFSET POINTS. RESET ZLAST(1)
C4      IF THE LAST (AND ALSO THE FIRST) OFFSET POINT IS WET..
C4
240      ZLAST(1, J)=ZO
250      INPTS(J)=L
        IF (L.EQ.0) GO TO 260
        IF (LWET.EQ.L) LWET=0
        IPOINT(J)=LWET+1
        LSTA=J
        IF (ISTA.EQ.0) ISTA=J
C3      260 CONTINUE
        IF (ISTA.EQ.0) GO TO 520
C3      FIND ENDS OF WETTED HULL. .
C3
        XXF      = X-COORDINATE FORWARD
        XXA      = X-COORDINATE AFT
C3
        XXF=XOFF(ISTA)

```

```

XXA=XOFF(LSTA)
IF (NPROF, EQ. 0) GO TO 410
C4
C4 SEARCH FOR ENDS USING THE PROFILE DATA..
C4
C4      XLAST    -- X-COORDINATE OF PREVIOUS PROFILE POINT
C4      XXSTA   -- X-COORDINATE OF PRESENT PROFILE POINT
C4      ETABAR   -- WAVE ELEVATION IN ABSOLUTE COORDINATES
C4      Y0       -- SUBMERGENCE OF PREVIOUS PROFILE POINT (LAST, EQ. 1)
C4      Y1       -- SUBMERGENCE OF PRESENT PROFILE POINT
C4      IEND=0   -- FORWARD END OF SHIP
C4      IEND=1   -- AFT END OF SHIP
C4      KEY=-1   -- SUBMERGENCE OF PRESENT PROFILE POINT UNKNOWN
C4      KEY=0    -- WAVE ELEVATION NOT COMPUTED
C4      KEY=1    -- WAVE ELEVATION COMPUTED
C4      LAST     -- KEY VALUE FOR PREVIOUS PROFILE POINT
C4      LWET=0   -- PREVIOUS PROFILE POINT WAS DRY (LAST, GE. 0)
C4      LWET=1   -- PREVIOUS PROFILE POINT WAS SUBMERGED (LAST, GE. 0)
C4
C4      XLAST=XPROF(1)
C4      LAST=-1
C4      DO 400 I=2, NPROF
C4          KEY=-1
C4          IEND=0
C4          XXSTA=XPROF(I)
C4          IF (XXSTA, GT, XXX) GO TO 270
C4          IEND=1
C4          IF (XXSTA, LT, XXA) GO TO 270
C4          IF (XLAST, GE, XXA) GO TO 390
270      KEY=0
C4          Y1=YPROF(I)*C(2, 2)+XXSTA*C(1, 2)-YY(2)
C4          IF (Y1, LT, -WVSUM) GO TO 310
C4          IF (Y1, GT, WVSUM) GO TO 280
C4          Y1=ETABAR(I)-Y1
C4          KEY=1
C4          IF (Y1, GE, 0.0) GO TO 310
C5
C5      POINT IS DRY.
C5
C5      280      IF (IEND, NE, 0) GO TO 300
C5          IF (LAST, LT, 0) GO TO 290
C5          IF (LWET, EQ, 0) GO TO 300
C5          IF (LAST, NE, 0) GO TO 340
C5      290      Y0=YPROF(I-1)*C(2, 2)+XLAST*C(1, 2)-YY(2)
C5          IF (Y0, GT, WVSUM) GO TO 300
C5          Y0=ETABAR(I-1)-Y0
C5          IF (Y0, GE, 0.0) GO TO 340
C5      300      LWET=0
C5          GO TO 380
C5
C5      POINT IS WET.
C5
C5      310      IF (IEND, NE, 0) GO TO 320
C5          XXF=XXSTA
C5          LWET=1
C5          GO TO 380
C5      320      IF (LAST, LT, 0) GO TO 330
C5          IF (LWET, NE, 0) GO TO 360
C5          IF (LAST, NE, 0) GO TO 340
C5      330      Y0=YPROF(I-1)*C(2, 2)+XLAST*C(1, 2)-YY(2)
C5          IF (Y0, LE, -WVSUM) GO TO 360

```

```

C YO=ETABAR(I-1)-YO
C IF (YO.GE.0.0) GO TO 360
C5
C5      INTERPOLATE FOR WATERLINE.
C5
C5 340  IF (KEY.NE.0) GO TO 350
C5      Y1=ETABAR(I)-Y1
C5      KEY=1
C5 350  XXSTA=(XPRODF(I-1)-XXSTA)/(Y1-Y0)+XXSTA
C5      IF (IEND.NE.0) GO TO 360
C5      IF (XXSTA.GT.XXF) XXF=XXSTA
C5      GO TO 370
C5 360  IF (XXSTA.LT.XXA) XXA=XXSTA
C5 370  LWET=IEND
C5 380  YO=Y1
C5 390  LAST=KEY
C5      XLAST=XXSTA
C400 CONTINUE
C410 IF (NFWD.NE.1) GO TO 420
C410 IF (XXF.LT.FWD) XXF=FWD
C420 IF (NAFT.NE.1) GO TO 430
C420 IF (XXA.GT.AFT) XXA=AFT

```

C3

---

### SECTION 3.0 ANOTHER INITIALIZATION

---

Resolve velocity vector into yawed and pitched coord's.  
 NOTE: Forces are calculated in local (ship) coordinate  
 system.

---

```

C430 VT(1)=VX
C430 VT(2)=VY*CTHETA-VZ*STHETA
C430 VT(3)=VZ*CTHETA+VY*STHETA
C430 VT(4)=YY(10)
C430 VT(5)=YY(11)*CTHETA-YV(12)*STHETA
C430 VT(6)=YY(12)*CTHETA+YY(11)*STHETA

```

---

Loop over wet stations ISTA to LSTA.  
 Also check to see if ship is out of water (SMALL)

---

LSAVE=0

```

C440 SMALL=(XXF-XXA)*1.0E-06
C440 IF (SMALL.LE.0.0) GO TO 520
C440 XXSTA=XXF
C440 DO 510 J=ISTA,LSTA

```

---

Section 4.1 - Get geometric station data, e.g. DX.

---

```

C450 XXFWD=XXSTA
C450 XXSTA=XOFF(J)
C450 IF (INPTS(J).EQ.0) GO TO 510
C450 YC=YY(2)+CT(1,2)*XXSTA
C450 IF (J.NE.LSTA) GO TO 331

```

```
XXAFT=XXA
GO TO 332
331 XXAFT=XOFF(J+1)
CONTINUE
DXFWD=XXFWD-XXSTA
DXAFT=XXSTA-XXAFT
DX=(DXFWD+DXAFT)/2.0
XA=XXSTA-DXAFT/3.0
XB=XXSTA+DXFWD/3.0
DX1=(DXFWD*XB+DXAFT*XA)/2.0
DX2=(DXFWD*XB**2+DXAFT*XA**2)/2.0+(DXFWD**3+DXAFT**3)/36.0
```

C-----  
C-----  
C-----  
Section 4.2 - Call KRYLOV by section (j) and get 2-D  
integrals for that station.

C-----  
C-----  
CALL KRYLOV (J)

C-----  
C-----  
Section 4.3 - Compute the sectional volumes and moments  
about center of mass.

C-----  
DVOL=AREA\*DX
ADX1=AREA\*DX1
ADX2=AREA\*DX2
YDX=YMOM\*DX
ZDX=ZMOM\*DX

C-----  
Load COMMON/SXGEOM/
AREAS(J)=AREA
DXS(J)=DX
DX1S(J)=DX1
DX2S(J)=DX2
YMOMS(J)=YMOM
ZMOMS(J)=ZMOM

C-----  
SECTION 5.0 - SHIP MOTION RELATED FORCES

C-----  
FBUOY(I,J) - Buoy force
FDAMP(I,J) Damping force
FADMA(I,J) - Added Mass Force for purposes of analysis  
only since the added mass actually goes  
on the left hand side of the Equations.

C-----  
Section 5.1 - Buoyancy Force

FBUOY(1,J)=CT(1,2)\*DVOL
FBUOY(2,J)=CT(2,2)\*DVOL
FBUOY(3,J)=0.
???? ^ ?????
FBUOY(4,J)=-CT(2,2)\*ZDX
FBUOY(5,J)=CT(1,2)\*ZDX

```
FBUOY(6, J)= CT(2, 2)*ADX1-CT(1, 2)*YDX
```

```
C-----  
C  
C Section 5.2 - Damping force
```

```
C  
C Get damping coefficients...  
C This section will be changed to reflect the  
C dependency on frequency of ship motion.
```

```
C  
C  
C HVH=COEFF(1, 2, J)/G  
C SVS=COEFF(2, 2, J)/G  
C RVR=COEFF(3, 2, J)/G  
C CCV=COEFF(4, 2, J)/G
```

```
C  
C  
C HVH=THVH(J, 21)/G  
C SVS=TSVS(J, 21)/G  
C RVR=TRVR(J, 21)/G  
C CCV=TCCV(J, 21)/G
```

```
C  
C  
C HAH=THAH(J, 21)  
C SAS=TSAS(J, 21)  
C RAR=TRAR(J, 21)  
C CCA=TCCA(J, 21)
```

```
C  
C  
C VS=VT(5)*ADX1-VT(3)*DVOL  
C VR=VT(4)*DVOL  
C FDAMP(1, J)=0.  
C FDAMP(2, J)=(VT(4)*ZDX-VT(2)*DVOL-VT(6)*ADX1)*HVH  
C FDAMP(3, J)=VS*SVS-VR*CCV  
C FDAMP(4, J)=VS*CCV-VR*RVR  
C FDAMP(5, J)=(VT(3)*ADX1-VT(5)*ADX2)*SVS+VT(4)*ADX1*CCV  
C FDAMP(6, J)=(VT(4)*ZMOM*DX1-VT(2)*ADX1-VT(6)*ADX2)*HVH
```

```
C-----  
C  
C Section 5.3 - Speed terms
```

```
C 5.3.1 - Speed terms associated with damping
```

```
C  
C UDAMP(1, J)=0.
```

```
C  
C UDAMP(2, J)=(2.*SPEED*YY(6))*HVH*D VOL  
C UDAMP(3, J)=-(2.*SPEED*YY(5))*SVS*D VOL  
C UDAMP(4, J)=0.  
C UDAMP(5, J)=(2.*SPEED*YY(5))*SVS*ADX1  
C UDAMP(6, J)=(2.*SPEED*YY(6))*HVH*ADX1
```

```
C  
C *** Extra speed terms from extended strip (X SCORES)
```

```
C U2TEMP=(YY(2)*DVOL+YY(6)*ADX1+SPEED*D VOL*  
C * (VT(6)/OMEGAX(1)**2)*(THVCX(J, 21)/G)*  
C * SPEED  
C UDAMP(2, J)=UDAMP(2, J)+U2TEMP  
C UDAMP(6, J)=UDAMP(6, J)+U2TEMP*(ADX1/D VOL)
```

```
C  
C 5.3.2 Speed terms associated with added mass
```

```
C  
C UADMA(1, J)=0.  
C UA21=(2.*SPEED*VT(6))*(HAH/G)*DVOL
```

```

1   UA22=(VT(4)*ZDX-VT(2)*DVOL-VT(6)*ADX1+SPEED*YY(6)
     *DVOL)*SPEED*(THACX(J,21)/G)
UADMA(2,J)=UA21-UA22
UA31=(-2.*SPEED*VT(5))*(SAS/G)*DVOL
UA32=(VS-SPEED*YY(5))*(TSACX(J,21)/G)*SPEED
UADMA(3,J)=UA31+UA32
UADMA(4,J)=-VR*SPEED*TRACX(J,21)/G
UA51=(2.*SPEED*VT(5))*(SAS/G)*ADX1
UA52=((SPEED*YY(5)*ADX1)+(VT(3)*ADX1-VT(5)*ADX2))
1   *SPEED*TSACX(J,21)/G
UADMA(5,J)=UA51+UA52
UA61=(2.*SPEED*VT(6))*(HAH/G)*ADX1
UA62=((SPEED*YY(6)*ADX1)+(VT(4)*ZMOM*DX1-VT(2)*
1   ADX1-VT(6)*ADX2))*SPEED*THACX(J,21)/G
UADMA(6,J)=UA61-UA62

```

C

```

YFYA=HAH*D VOL+YFYA
ZFZA=SAS*D VOL+ZFZA
XMZA=CCA*D VOL+XMZA
XMXR=RAR*D VOL+XMXR
XMYR=XMYR-CCA*ADX1
YMZA=YMZA-SAS*ADX1
YMYR=SAS*ADX2+YMYR
ZMYA=HAH*ADX1+ZMYA
ZMZR=HAH*ADX2+ZMZR

```

C

C

C

C

#### Section 5.4 - Force due to weight of ship

C

```

XFW=-CT(1,2)*DISPL
YFW=-CT(2,2)*DISPL

```

C

C

C

#### Section 7.2 - So called "flare" force

C

```

IF(TT.EQ.TTOLD(J)) GO TO 721
TNEW(J)=TSTA(J)
TAVG=TSTA(J)
CALL TXIT(TAVG, IT, TX)
CNEW(J)=COX(IT, TX, 11, 1, 1, J)*ARX(IT, TX, J)/G
TTNEW(J)=TT
DC=CNEW(J)-COLD(J)
DT=TNEW(J)-TOLD(J)
DTT=TTNEW(J)-TTOLD(J)
TOLD(J)=TNEW(J)
TTOLD(J)=TTNEW(J)
COLD(J)=CNEW(J)

```

C

```

IF (DT.GT.0. . AND. DTT.NE.0.) THEN !Relative Velocity indicates immersi
FFLAR(2,J)=(DT/DTT)**2*(DC/DT)*DX
FFLAR(6,J)=(DT/DTT)**2*(DC/DT)*DX1
ELSE ! Relative velocity indicates emergence
FFLAR(2,J)=0.
FFLAR(6,J)=0.

```

C END IF

C 721 CONTINUE !Skip to here when TT=TTOLD

C-----  
C If there are no waves, skip over the wave loop -  
C [Do 500] and go to 510 (the other side of the section  
C loop).  
C IF (NWAVES, EQ, 0) GO TO 510

C-----  
C SECTION 6.0 - WAVE-INDUCED FORCES

C-----  
C IF (LSAVE, NE, 0) GO TO 450  
C IF (DXFWD, LT, SMALL) GO TO 441  
C DDXFWD=1.0/DXFWD

C GO TO 460

441 DDXFWD=0.0

C GO TO 460

450 DDXFWD=DDXAFT

460 IF (DXAFT, LT, SMALL) GO TO 461

C DDXAFT=1.0/DXAFT

C GO TO 470

461 DDXAFT=0.0

C-----  
C 470 LSAVE=LSTA-J

C IF (LSAVE, NE, 0) LSAVE=INPTS(J+1)

C-----  
C Loop over waves (frequency index K)

C-----  
C DO 500 K=1, NWAVES

C-----  
C Section 6.1 - Compute integration multipliers...  
C DXCOS, DXSIN, DX1COS, DX1SIN.

C-----  
C XWC=XW(K)  
C XWSTA=XXSTA-XWC  
C SQSTA=XWSTA\*\*2  
C XWAFT=XXAFT-XWC  
C SQAFT=XWAFT\*\*2  
C XWFWD=XXFWD-XWC  
C SQFWD=XWFWD\*\*2  
C DXWAFT=XWAFT\*DDXAFT  
C DXWFWD=XWFWD\*DDXFWD  
C WCOSB=CXK(K)

C-----  
C 472 IF (JSAVE(K), EQ, 0) GO TO 472  
C COSSTA=COSJ(K)  
C SINSTA=SINJ(K)

C GO TO 473

C CONTINUE

C ARGSTA=WCOSB\*XWSTA

C COSSTA=COS(ARGSTA)

C SINSTA=SIN(ARGSTA)

C 473 CONTINUE

```

C           IF (ABS(WCOSB*DX). GT. 0.01) GO TO 480
C
C           DXCOS=DX*COSSTA
C           DXSIN=DX*SINSTA
C           DX1COS=DX1*COSSTA
C           DX1SIN=DX1*SINSTA
C           JSAVE(K)=0
C           GO TO 490
C
C   480      WCOSB2=2.0/WCOSB
C           XCSTA=COSSTA*XWSTA
C           XSSTA=SINSTA*XWSTA
C
C           IF (JSAVE(K). EQ. 0) GO TO 481
C           COSFWD=COSJJ(K)
C           SINFWD=SINJJ(K)
C           DWCFWD=DWC(K)
C           DWSFWD=DWS(K)
C           XCIFWD=XCI(K)
C           XSIFWD=XSI(K)
C           GO TO 482
C
C   481      ARGFWD=WCOSB*XWFWD
C           COSFWD=COS(ARGVWD)
C           SINFWD=SIN(ARGVWD)
C           DWCFWD=(COSFWD-COSSTA)/WCOSB
C           DWSFWD=(SINFWD-SINSTA)/WCOSB
C           XCIFWD=(SINFWD*XWFWD-XSSTA+DWCFWD)*DDXFWD
C           XSIFWD=(XCSTA-COSFWD*XWFWD+DWSFWD)*DDXFWD
C
C   482      ARGAFT=WCOSB*XWAFT
C           COSAFT=COS(ARGAFT)
C           SINAFT=SIN(ARGAFT)
C           DWCAFT=(COSSTA-COSAFT)/WCOSB
C           DWSAFT=(SINSTA-SINAFT)/WCOSB
C           XCIAFT=(XSSTA-SINAFT*XWAFT+DWCAFT)*DDXAFT
C           XSIAFT=(COSAFT*XWAFT-XCSTA+DWSAFT)*DDXAFT
C
C
C   1        DXCOS=(XCIAFT-XCIFWD)/WCOSB-DXWAFT*DWSAFT+DXWFWD*DWSFWD
C           DXSIN=(XSIAFT-XSIFWD)/WCOSB+DXWAFT*DWCAFT-DXWFWD*DWC
C           DX1COS=XWC*DXCOS+((SQSTA*SINSTA-SQAFT*SINAFT)*DDXAFT+(SQSTA*
C           SINSTA-SQFWD*SINFWD)*DDXFWD+(XSIFWD-XSIAFT)*WCOSB2+XWFWD*XCI
C           FWD-XWAFT*XCIAFT)/WCOSB
C           DX1SIN=XWC*DXSIN+((SQFWD*COSFWD-SQSTA*COSSTA)*DDXFWD+(SGAFT*
C           COSAFT-SQSTA*COSSTA)*DDXAFT+(XCIAFT-XCIFWD)*WCOSB2+XWFWD*XSI
C           FWD-XWAFT*XSIAFT)/WCOSB
C
C           JSAVE(K)=LSAVE
C           IF (LSAVE.EQ.0) GO TO 490
C           COSJ(K)=COSAFT
C           SINJ(K)=SINAFT
C           COSJJ(K)=COSSTA
C           SINJJ(K)=SINSTA
C           DWC(K)=DWCAFT
C           DWS(K)=DWSAFT
C           XCI(K)=XCIAFT
C           XSI(K)=XSIAFT
C
C   490      CONTINUE
C           EXPSTA=EXP(WN(K)*YC)*WVAMP(K)

```

```
DXCOS=DXCOS*EXPSTA  
DXSIN=DXSIN*EXPSTA  
DX1COS=DX1COS*EXPSTA  
DX1SIN=DX1SIN*EXPSTA
```

C3

```
C-----  
C-----  
C Section 6.2 - Compute exciting forces (wave dynamic  
C pressure plus diffraction force)  
C-----  
C-----
```

```
C-----  
C-----  
C HVH=CDEFF(1, 2, J)/WVFRE(K)  
C SVS=CDEFF(2, 2, J)/WVFRE(K)  
C RVR=CDEFF(3, 2, J)/WVFRE(K)  
C CCV=CDEFF(4, 2, J)/WVFRE(K)  
C-----  
C-----
```

```
C-----  
C-----  
C HAH=THAH(J, K)  
C HAH=HAH+1.  
C SAS=TSAS(J, K)  
C SAS=SAS+1.  
C RAR=TRAR(J, K)  
C CCA=TCCA(J, K)  
C-----  
C-----
```

```
C-----  
C-----  
C HVH=THVH(J, K)/WVFRE(K)  
C SVS=TSVS(J, K)/WVFRE(K)  
C RVR=TRVR(J, K)/WVFRE(K)  
C CCV=TCCV(J, K)/WVFRE(K)  
C-----  
C-----
```

```
AH1=CYK(K)*ZSO(K)-CCK(K)*ZCO(K)  
AH2=CCK(K)*ZSO(K)+CYK(K)*ZCO(K)  
AS1=CZK(K)*ZSO(K)  
AS2=CZK(K)*ZCO(K)  
AR1=CZK(K)*ZSY(K)+CCK(K)*ZCZ(K)-CYK(K)*ZSZ(K)  
AR2=CZK(K)*ZCY(K)-CCK(K)*ZSZ(K)-CYK(K)*ZCZ(K)  
FWVEX(1, J)=(CXK(K)*ZSO(K)-CSK(K)*ZCO(K))*DXCOS  
1 +(CXK(K)*ZCO(K)+CSK(K)*ZSO(K))*DXSIN+FWVEX(1, J)  
YF1=AH1*HAH+AH2*HVH  
YF2=AH2*HAH-AH1*HVH  
FWVEX(2, J)=YF1*DXCOS+YF2*DXSIN+FWVEX(2, J)  
ZF1=AS1*SAS+AS2*SVS+(AS1*CCA+AS2*CCV)*WN(K)  
ZF2=AS2*SAS-AS1*SVS+(AS2*CCA-AS1*CCV)*WN(K)  
FWVEX(3, J)=ZF1*DXCOS+ZF2*DXSIN+FWVEX(3, J)  
FWVEX(4, J)=(AR1+(AS1*RAR+AS2*RVR)*WN(K)+AS1*CCA+  
1 AS2*CCV)*DXCOS+(AR2+(AS2*RAR-AS1*RVR)*WN(K)+AS2*CCA  
2 -AS1*CCV)*DXSIN+FWVEX(4, J)  
FWVEX(5, J)=(CXK(K)*ZSZ(K)-CSK(K)*ZCZ(K))*DXCOS+  
1 (CXK(K)*ZCZ(K)+CSK(K)*ZSZ(K))*DXSIN-ZF1*DX1COS-ZF2  
2 *DX1SIN+FWVEX(5, J)  
FWVEX(6, J)=(CSK(K)*ZCY(K)-CXK(K)*ZSY(K))*DXCOS-  
1 (CSK(K)*ZSY(K)+CXK(K)  
2 *ZCY(K))*DXSIN+YF1*DX1COS+YF2*DX1SIN+FWVEX(6, J)
```

```

C3
C
C-----6.3 Speed dependent wave-exciting terms-----
C
C DADX=SPEED*THACX(J,K)/WVFRE(K) !Turns acc.'s into Vel's
C UWVEX(2,J)=AH1*DADX*DXSIN-AH2*DADX*DXCOS+UWVEX(2,J)
C Another speed term - spatial derivative of damping in x
C DCDX=SPEED*(THVCX(J,K)/G)*DVOL*WVFRE(K)/OMEGAX(1)
C UWVEX(2,J)=UWVEX(2,J)+DCDX*ETAY(J,K)
C UZF1=AS1*TSACX(J,K)+AS2*TSVCX(J,K)
C UZF2=AS2*TSACX(J,K)-AS1*TSVCX(J,K)
C UWVEX(3,J)=(-UZF1*DXSIN+UZF2*DXCOS)*(SPEED/WVFRE(K))
C           +UWVEX(3,J)

1   UWVEX(4,J)=0.      ! Modify this
1   UWVEX(5,J)=(-UZF1*DX1SIN+UZF2*DX1COS)*(SPEED/WVFRE(K))
1           + UWVEX(5,J)
1   UWVEX(6,J)=AH1*DADX*DX1SIN-AH2*DADX*DX1COS
C DCDX1=SPEED*(THVCX(J,K)/G)*ADX1*WVFRE(K)/OMEGAX(1)
C UWVEX(6,J)=DCDX1*ETAY(J,K)+UWVEX(6,J)
C-----500 CONTINUE
C-----510 CONTINUE

C-----SECTION 7.0 - OTHER FORCES
C-----Force resulting from acceleration caused by the rotating
C-----coordinates.

C-----YA=VT(6)*VT(1)-VT(4)*VT(3)
C-----YA=YA/G
C-----ZA=VT(4)*VT(2)-VT(5)*VT(1)
C-----ZA=ZA/G
C-----XFN=0.
C-----YFN=YFYA*YA
C-----ZFN=ZFZA*ZA
C-----XMN=XMZA*ZA
C-----YMN=YMZA*ZA
C-----ZMN=ZMYA*YA

C-----SECTION 8.0 - INTEGRATE FORCES ALONG LENGTH OF HULL
C-----Section 8.1 - Integrate buoyancy force

C-----DO 801 J=ISTA, LSTA
C-----XFB=FBUDY(1,J)+XFB
C-----YFB=FBUDY(2,J)+YFB
C-----ZFB=FBUDY(3,J)+ZFB
C-----XMB=FBUDY(4,J)+XMB

```

```

YMB=FBUOY(5,J)+YMB
ZMB=FBUOY(6,J)+ZMB
CONTINUE
C
C-----  

C Section 8.2 - Integrate damping force  

C-----  

C
DO 802 J=ISTA,LSTA
XFD=FDAMP(1,J)+XFD
YFD=FDAMP(2,J)+YFD
ZFD=FDAMP(3,J)+ZFD
XMD=FDAMP(4,J)+XMD
YMD=FDAMP(5,J)+YMD
ZMD=FDAMP(6,J)+ZMD
802 CONTINUE
C
C-----  

C Section 8.3 - Integrate exciting force  

C-----  

C
DO 803 J=ISTA,LSTA
XFX=FWVEX(1,J)+XFX
YFX=FWVEX(2,J)+YFX
ZFX=FWVEX(3,J)+ZFX
XMX=FWVEX(4,J)+XMX
YMX=FWVEX(5,J)+YMX
ZMX=FWVEX(6,J)+ZMX
803 CONTINUE
C
C-----  

C Section 8.4 - Integrate Speed Related forces  

C-----  

C
IF(JOBFO(2).NE.1) GO TO 814
DO 804 J=ISTA,LSTA
XFU=UDAMP(1,J)+UADMA(1,J)+UWVEX(1,J)+XFU
YFU=UDAMP(2,J)+UADMA(2,J)+UWVEX(2,J)+YFU
ZFU=UDAMP(3,J)+UADMA(3,J)+UWVEX(3,J)+ZFU
XMU=UDAMP(4,J)+UADMA(4,J)+UWVEX(4,J)+XMU
YMU=UDAMP(5,J)+UADMA(5,J)+UWVEX(5,J)+YMU
ZMU=UDAMP(6,J)+UADMA(6,J)+UWVEX(6,J)+ZMU
804 CONTINUE
814 CONTINUE           !Go directly here to skip over
C
C-----  

C Section 8.5 - Integrate flare force  

C-----  

C
IF(JOBFO(3).NE.1) GO TO 815
DO 805 J=ISTA,LSTA
YFF=FFLAR(2,J)+YFF
ZMF=FFLAR(6,J)+ZMF
805 CONTINUE
815 CONTINUE           !Directly to here to skip over
C
C-----  

C C4      SET UP MATRIX OF FORCE COEFFICIENTS FOR FORCES AND ACCELERATIONS

```

```

C4      IN SHIP COORDINATE DIRECTIONS..
C4
C4      520 CONTINUE
C4
C
C-----  

C      SECTION 9.0 - TOTAL FORCES
C
C      Add up forces. Then resolve forces and moments into the
C      ship offset coordinate system.
C
C-----  

C
C      XFT=XFB+XFD+XFX+XFN+XFW+XFU
C      YFT=YFB+YFD+YFX+YFN+YFW+YFU+YFF
C      ZFT=ZFB+ZFD+ZFX+ZFN+ZFU
C      XMT=XMB+XMD+XMX+XMN+XMU
C      YMT=YMB+YMD+YMX+YMN+YMU
C      ZMT=ZMB+ZMD+ZMX+ZMN+ZMU+ZMF
C
C      XF=XFT*GAMMA
C      YF=YFT*GAMMA
C      TEMP=YF
C      ZF=ZFT*GAMMA
C      YF=YF*CTHETA+ZF*STHETA
C      ZF=ZF*CTHETA-TEMP*STHETA
C      XM=XMT*GAMMA
C      TEMP=YMT
C      YM=(YMT*CTHETA+ZMT*STHETA)*GAMMA
C      ZM=(ZMT*CTHETA-TEMP*STHETA)*GAMMA
C
C-----  

C      SECTION 10.0 - LOAD MASS/INERTIA MATRIX A(I,J)
C
C-----  

C
C      A(2, 4)=0. 0
C      DO 530 I=1, 9
C          AM(I)=RHO*AM(I)
C530 CONTINUE
C      CC=CTHETA**2
C      CS=CTHETA*STHETA
C      SS=STHETA**2
C      A(2, 2)=YFYA*CC+ZFZA*SS+SMASS
C      A(2, 3)=(ZFZA-YFYA)*CS
C      A(3, 2)=A(2, 3)
C      A(2, 5)=ZMYA*CS
C      A(2, 6)=ZMYA*CC
C      A(3, 3)=ZFZA*CC+YFYA*SS+SMASS
C      A(3, 4)=XMZA*CTHETA
C      A(4, 3)=A(3, 4)
C      A(4, 2)=XMZA*STHETA
C      A(4, 4)=XMXR+PMI(1, 1)
C      A(4, 5)=XMYR*CTHETA+PMI(1, 2)
C      A(5, 4)=A(4, 5)
C      A(4, 6)=PMI(1, 3)-XMYR*STHETA
C      A(6, 4)=A(4, 6)
C      A(5, 2)=(ZMYA+YMZA)*CS

```

```
A(3,6)=-A(5,2)
A(6,3)=A(3,6)
A(5,3)=YMA*CC-ZMYA*SS
A(3,5)=A(5,3)
A(5,5)=YMYR*CC+ZMZR*SS+PMI(2,2)
A(5,6)=(ZMZR-YMYR)*CS+PMI(2,3)
A(6,5)=A(5,6)
A(6,2)=ZMYA*CC-YMA*SS
A(6,6)=ZMZR*CC+YMYR*SS+PMI(3,3)
RETURN
```

```
C      END
```

SUBROUTINE HULL  
 This subroutine calculates hull girder loads

```

COMMON /C      / C(3,3)
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
COMMON /      / NWAVES, WVSUM,
1           WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2           WN(20), WNX(20), WNZ(20),
3           CSK(20), CCK(20), CXK(20),
4           CYK(20), CZK(20), XW(20)
COMMON /      / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1           XOFF(25), YOFF(25,25), ZOFF(25,25),
2           XPROF(51), YPROF(51)
* COMMON/COEFFX/THAH(25,21), TSAS(25,21), TRAR(25,21), TCCA(25,21),
*           THVH(25,21), TSVS(25,21), TRVR(25,21), TCCV(25,21),
*           THACX(25,21), THVCX(25,21), TSACX(25,21), TSVCX(25,21),
*           TRACX(25,21), TCACX(25,21), THVCY(25,21),
*           ITP(25), TXP(25), IFP(21), FXP(21)
COMMON /FORCE / XF, YF, ZF, XM, YM, ZM
REAL FORCE(6)
EQUIVALENCE (FORCE(1),XF)
COMMON /LHS   / Y(13)
COMMON /MASS  / RHO, G, GAMMA
COMMON /MASS  / DISPL, SMASS, XCG, YCG, ZCG,
1           AMX, AMY, AMZ, RADII(6)
COMMON /MASS  / PMI(3,3)
COMMON/RESIST/SPEED
COMMON /V      / VX, VY, VZ
COMMON/SXPROP/ SEGMAS(26), SEGMOX(26), STRMAS(26), STRMOM(26),
*           STRMOX(26), XBAR(26), YBAR(26), SEGWT(26), NWTSTA
COMMON/SXFOR/ FBUDY(6,25), FDAMP(6,25), FADMA(6,25), FWVEX(6,25),
*           UDAMP(6,25), UADMA(6,25), UWVEX(6,25), FFLAR(6,25)
COMMON/SXGEOM/ AREAS(25), DXS(25), DX1S(25), DX2S(25),
*           YMOMS(25), ZMOMS(25), ISTA, LSTA
COMMON/ACCEL/ACC(6)
COMMON/LOADS/ SIN2(25), SIN3(25), SIN4(25), SIN5(25), SIN6(25),
1           V2(25), V3(25), V4(25), V5(25), V6(25),
2           RED(6,25)
COMMON/OPTION/JOBCO, JOBFO(10)

```

#### SECTION 1.0 GET SECTIONAL INERTIA/MOMENT OF INERTIAS

```

DO 90 J=1,MSTA
XBAR(J)=XOFF(J)
STRMAS(J)=SEGMAS(J)
SIN2(J)=0.
SIN3(J)=0.
SIN4(J)=0.
SIN5(J)=0.
SIN6(J)=0.
DO 91 I=1,6
RED(I,J)=0.
CONTINUE
CONTINUE

DO 100 J=1,MSTA
DSTRPI=XOFF(J)
DO 101 JJ=1,J

```

91  
90  
C

```

C
C      TVACCL=ACC(2)+XBAR(JJ)*ACC(6)
C      THACCL=ACC(3)-XBAR(JJ)*ACC(5)+YBAR(JJ)*ACC(4)
C-----NOTE!!! We are adding in weight of the section
C      by including gravitational acceleration. This
C      is different from standard strip theory load
C      computations. (They compute wave induce dynamic
C      loads) We are computing total loads at each time
C      step... We have the TOTAL HYDROSTATIC RESTORING
C      force not just the change due to unit wave/motion
C      [see eq. 70 STF METHOD/TRANS SNAME '70]
C
C      GVACCL=-G*COS(Y(4))
C      GHACCL=G*SIN(Y(4))
C
C      HACCL=-THACCL+GHACCL
C      VACCL=-TVACCL+GVACCL
C
C
C      SIN2(J)=STRMAS(JJ)*VACCL+SIN2(J)
C      SIN3(J)=STRMAS(JJ)*HACCL+SIN3(J)
C      SIN4(J)=STRMOX(JJ)*ACC(4)-((STRMAS(JJ)*YBAR(JJ))*  

C      1          (ACC(3)+XBAR(JJ)*ACC(5)))+SIN4(J)
C      DSTRPI=XOFF(J)-(.5*DXS(J))
C      ZETMX=XBAR(JJ)-DSTRPI
C      SINS(J)=ZETMX*STRMAS(JJ)*HACCL+SIN5(J)
C      SIN6(J)=ZETMX*STRMAS(JJ)*VACCL+SIN6(J)
C
C      101    CONTINUE
C-----
C-----  

C-----  

C      100    CONTINUE
C-----  

C-----  

C      SECTION 2.0  GET ADDED MASS FORCES FADMA( , )
C-----  

C-----  

C
C      DO 200 J=1,MSTA
C      DO 200 I=1,6
C      FADMA(I,J)=0.
C
C      200    CONTINUE
C
C      DO 201 J=ISTA,LSTA
C
C      AREA=AREAS(J)
C      DX=DXS(J)
C      DX1=DX1S(J)
C      DX2=DX2S(J)
C      YMOM=YMOMS(J)
C      ZMOM=ZMOMS(J)
C
C      DVOL=AREA*DX
C      ADX1=AREA*DX1
C      ADX2=AREA*DX2
C      YDX=YMOM*DX
C      ZDX=ZMOM*DX

```

```

C
      HAH=THAH(J,21)/G
      SAS=TSAS(J,21)/G
      RAR=TRAR(J,21)/G
      CCA=TCCA(J,21)/G
C
C
      AS=ACC(5)*ADX1-ACC(3)*DVOL
      AR=ACC(4)*DVOL
      FADMA(1,J)=0.
      FADMA(2,J)=(ACC(4)*ZDX-ACC(2)*DVOL-ACC(6)*ADX1)*HAH
      FADMA(3,J)=AS*SAS-AR*CCA
      FADMA(4,J)=AS*CCA-AR*RAR
      FADMA(5,J)=(ACC(3)*ADX1-ACC(5)*ADX2)*SAS+ACC(4)
      *ADX1*CCA
      FADMA(6,J)=(ACC(4)*ZMOM*DIX1-ACC(2)*ADX1-
      ACC(6)*ADX2)*HAH
      1
      1
C
C
      201    CONTINUE
C
C      SECTION 3.0   GET HYDRO FORCES (CALL THEM RED) AND THEN
C      GET LOADS
C-----+
C
      DO 900 J=1,MSTA
900    CONTINUE
C
      DO 300 I=2,3
      DO 301 J=1,MSTA
      REDSUM=0.
      DO 302 JJ=1,J
      REDSUM=-FBUOY(I,JJ)-FDAMP(I,JJ)-FADMA(I,JJ)-FWVEX(I,JJ)
      *          +REDSUM
      *          UTERMS=-UDAMP(I,JJ)-UADMA(I,JJ)-UWVEX(I,JJ)
      *          FTERMS=-FFLAR(I,JJ)
      IF(JOBFO(2).EQ.1) REDSUM=REDSUM+UTERMS
      IF(JOBFO(3).EQ.1) REDSUM=REDSUM+FTERMS
302    CONTINUE
      RED(I,J)=REDSUM*GAMMA
301    CONTINUE
300    CONTINUE
C
C-----+
C
C      Now do moments
C
      DO 310 IX=5,6
      IF(IX.EQ.5) I=3
      IF(IX.EQ.6) I=2
      DO 311 J=1,MSTA
      DSTRPI=XOFF(J)
      DSTRPI=XOFF(J)-( .5*DXS(J))
      REDSUM=0.
C
      DO 312 JJ=1,J
C
      ARMJJ=XBAR(JJ)
      ARMX=ARMJJ-DSTRPI
      FDARM=FDAMP(I,JJ)*ARMX
      FWARM=FWVEX(I,JJ)*ARMX

```

```
FBARM=FBUDY(I, JJ)*ARMX
FAARM=FADMA(I, JJ)*ARMX
FUARM=(UADMA(I, JJ)+UDAMP(I, JJ)+UWVEX(I, JJ))*ARMX
FFARM=FFLAR(I, JJ)*ARMX
C
      REDSUM=-FBARM-FDARM-FAARM-FW\RM+REDSUM
      IF(JOBFO(2).EQ.1) REDSUM=REDSUM-FUARM
      IF(JOBFO(3).EQ.1) REDSUM=REDSUM-FFARM
 312    CONTINUE
C
      RED(IX, J)=REDSUM*GAMMA
C
 311    CONTINUE
 310    CONTINUE
C
C-----DO 305 J=1,MSTA
      V2(J)=SIN2(J)-RED(2, J)
      V3(J)=SIN3(J)-RED(3, J)
      V4(J)=SIN4(J)-RED(4, J)
      V5(J)=SIN5(J)-RED(5, J)
      V6(J)=SIN6(J)-RED(6, J)
C
 305    CONTINUE
C
C-----OUTPUT FORCES FOR EACH SECTION
      RETURN
 69      FORMAT(1X, I2, 1X, 6F15. 4)
      END
```

## C SUBROUTINE KRYLOV (J)

```

COMMON /      / NWAVES, WVSUM,
1          / WVAMP(20), WVFRE(20), WVDIR(20), WVPHA(20),
2          / WN(20), WNX(20), WNZ(20),
3          / CSK(20), CCK(20), CXK(20),
4          / CYK(20), CZK(20), XW(20)
COMMON /      / MSTA, NPROF, NFWD, NAFT, LPTS(25),
1          / XOFF(25), YOFF(25, 25), ZOFF(25, 25),
2          / XPROF(51), YPROF(51)
COMMON /      / INPTS(25), IPOINT(25), YWET(25, 25), ETA(25, 25),
1          / ZLAST(25, 25), ZWET(25, 25), ZNEXT(25, 25)
COMMON /      / ZCO(20), ZSO(20), ZCY(20), ZSY(20),
1          / ZCZ(20), ZSZ(20)
COMMON /      / DZK(20)
COMMON /      / JSAVE(20), COSJ(20), SINJ(20),
$          / COSJJ(20), SINJJ(20),
1          / DWC(20), DWS(20), XCI(20), XSI(20)
COMMON /      / ISAVE(20), CSI(20), SNI(20),
$          / CSII(20), SNII(20),
1          / DKC(20), DKS(20), ZCI(20), ZSI(20)
COMMON / AREA / AREA, YMOM, ZMOM
AREA=0. 0
YMOM=0. 0
ZMOM=0. 0
KSAVE=0
DO 110 K=1, NWAVES
    ZCO(K)=0. 0
    ZSO(K)=0. 0
    ZCY(K)=0. 0
    ZSY(K)=0. 0
    ZCZ(K)=0. 0
    ZSZ(K)=0. 0
    ISAVE(K)=0
110 CONTINUE
LI=INPTS(J)
II=IPOINT(J)
LAST=II-1
IF (LAST, EQ, 0) LAST=LI
111 DO 190 I=II, LI
    ETA1=ETA(I, J)
    Y1=YWET(I, J)
    Z0=ZLAST(I, J)
    Z1=ZWET(I, J)
    Z2=ZNEXT(I, J)
C3
    DZ0=Z1-Z0
    DZ2=Z2-Z1
    DZ=(Z2-Z0)/2. 0
    ZA=Z1-DZ0/3. 0
    ZB=Z1+DZ2/3. 0
    DZ1=(DZ2*ZB+DZ0*ZA)/2. 0
    AREA=AREA+(ETA1-Y1)*DZ
    ZMOM=ZMOM+(ETA1-Y1)*DZ1
    YMOM=(ETA1**2-Y1**2)/2. 0*DZ+YMOM
    IF (NWAVES, EQ, 0) GO TO 190
C
    IF (KSAVE, EQ, 0) GO TO 112
    SQ0=SQ1
    SQ1=SQ2
    DDZ0=DDZ2

```

```

      GO TO 130
112   SQ0=Z0**2
      SQ1=Z1**2
      IF (DZ0.EQ.0.0) GO TO 120
      IF ((DZ2/DZ0).GT.1.0E+06) GO TO 120
      DDZ0=1.0/DZ0
      DZZ0=Z0*DDZ0
      GO TO 130
120   DDZ0=0.0
      DZZ0=0.0
130   IF (DZ2.EQ.0.0) GO TO 140
      IF ((DZ0/DZ2).GT.1.0E+06) GO TO 140
      DDZ2=1.0/DZ2
      DZZ2=Z2*DDZ2
      GO TO 150
140   DDZ2=0.0
      DZZ2=0.0
150   SQ2=Z2**2
      KSAVE=0
      IF (I.EQ.LAST) GO TO 151
      IN=I
      IF (IN.EQ.LI) IN=0
      IF(Z1.EQ.ZLAST(IN+1,J).AND.Z2.EQ.ZWET(IN+1,J)) KSAVE=1
CONTINUE
      IF(ETA1.GT.0.0.AND.Y1.GT.0.0) ETA1=Y1
      DO 180 K=1,NWAVES
         CK=CCK(K)
         YK=CYK(K)
         ZK=czk(k)
         EE=EXP(CK*ETA1)
         EY=EXP(CK*Y1)
         ARG=YK*ETA1
         CE=COS(ARG)
         SE=SIN(ARG)
         ARG=YK*Y1
         CY=COS(ARG)
         SY=SIN(ARG)
         D=CK**2+YK**2
         CK=CK/D
         YK=YK/D
         COSE=(CK*CE+YK*SE)*EE
         SINE=(CK*SE-YK*CE)*EE
         COSY=(CK*CY+YK*SY)*EY
         SINY=(CK*SY-YK*CY)*EY
         YCO=COSE-COSY
         YSO=SINE-SINY
         YCY=ETA1*COSE-Y1*COSY-CK*YCO-YK*YSO
         YSY=ETA1*SINE-Y1*SINY-CK*YSO+YK*YCO
C
      IF (ISAVE(K).EQ.0) GO TO 152
      COS1=CSI(K)
      SIN1=SNI(K)
      GO TO 153
152   ARG1=ZK*Z1
      COS1=COS(ARG1)
      SIN1=SIN(ARG1)
CONTINUE
      IF (ABS(ZK*DZ).GT.0.01) GO TO 160
      DZCOS=DZ*COS1

```

```

DZSIN=DZ*SIN1
DZ1COS=DZ1*COS1
DZ1SIN=DZ1*SIN1
ISAVE(K)=0
GO TO 170

C 160      ZK2=DZK(K)
            ZCOS1=COS1*Z1
            ZSIN1=SIN1*Z1

C      IF (ISAVE(K). EQ. 0) GO TO 161
            COSO=CSII(K)
            SINO=SNII(K)
            DKCO=DKC(K)
            DKS0=DKS(K)
            ZCIO=ZCI(K)
            ZSIO=ZSI(K)
            GO TO 162

C 161      ARGO=ZK*ZO
            COSO=COS(ARGO)
            SINO=SIN(ARGO)
            DKCO=(COS1-COSO)/ZK
            DKS0=(SIN1-SINO)/ZK
            ZCIO=(ZSIN1-SINO*ZO+DKCO)*DDZO
            ZSIO=(COSO*ZO-ZCOS1+DKS0)*DDZO

C 162      ARG2=ZK*Z2
            COS2=COS(ARG2)
            SIN2=SIN(ARG2)
            DKC2=(COS2-COS1)/ZK
            DKS2=(SIN2-SIN1)/ZK
            ZCI2=(SIN2*Z2-ZSIN1+DKC2)*DDZ2
            ZSI2=(ZCOS1-COS2*Z2+DKS2)*DDZ2

C      DZCOS=(ZCIO-ZCI2)/ZK-DZZ0*DKS0+DZZ2*DKS2
            DZSIN=(ZSIO-ZSI2)/ZK+DZZ0*DKCO-DZZ2*DKC2
            DZ1COS=((SQ1*SIN1-SQ0*SINO)*DDZO+(SQ1*SIN1-SQ2*SIN2)*DDZ2+(Z
            SI2-ZSIO)*ZK2+Z2*ZCI2-Z0*ZCIO)/ZK
            DZ1SIN=((SQ2*COS2-SQ1*COS1)*DDZ2+(SQ0*COS0-SQ1*COS1)*DDZO+(Z
            CIO-ZCI2)*ZK2+Z2*ZSI2-Z0*ZSIO)/ZK

C      ISAVE(K)=KSAVE
            IF (KSAVE. EQ. 0) GO TO 170
            CSI(K)=COS2
            SNI(K)=SIN2
            CSII(K)=COS1
            SNII(K)=SIN1
            DKC(K)=DKC2
            DKS(K)=DKS2
            ZCI(K)=ZCI2
            ZSI(K)=ZSI2

C 170      CONTINUE
C      ZCO(K)=ZCO(K)+DZCOS*YCO-DZSIN*YS0
            ZSO(K)=ZSO(K)+DZCOS*YS0+DZSIN*YCO
            ZCY(K)=ZCY(K)+DZCOS*YCY-DZSIN*YSY
            ZSY(K)=ZSY(K)+DZCOS*YSY+DZSIN*YCY
            ZCZ(K)=ZCZ(K)+DZ1COS*YCO-DZ1SIN*YS0
            ZSZ(K)=ZSZ(K)+DZ1COS*YS0+DZ1SIN*YCO

```

```

180      CONTINUE
190  CONTINUE
    IF (LI.EQ.LAST) RETURN
    LI=LAST
    II=1
    GO TO 111
C
    END
    FUNCTION LNEQF(M, N, N1, A, B, DTRMNT, Z)
C.. SOLVES SIMULTANEOUS LINEAR EQUATIONS BY GAUSSIAN REDUCTION.
C.. FORTRAN IV EQUIVALENT OF LNEQS.
    REAL A(M,M),B(M,M),Z(M),DTRMNT,RMAX,RNEXT,W,DOV
    NM1=N-1
    DO 200 J=1,NM1
        J1=J+1
C.. FIND ELEMENT OF COL J, ROWS J-N, WHICH HAS MAX ABSOLUTE VALUE.
        LMAX=J
        RMAX=ABS(A(J,J))
        DO 110 K=J1,N
            RNEXT=ABS(A(K,J))
            IF (RMAX.GE.RNEXT) GO TO 110
            RMAX=RNEXT
            LMAX=K
110      CONTINUE
        IF (LMAX.NE.J) GO TO 120
C.. MAX ELEMENT IN COLUMN IS ON DIAGONAL
        IF (A(J,J)) 150,290,150
C.. MAX ELEMENT IS NOT ON DIAGONAL. EXCHANGE ROWS J AND LMAX.
120      DO 130 L=J,N
        W=A(J,L)
        A(J,L)=A(LMAX,L)
130      A(LMAX,L)=W
        DO 140 L=1,N1
        W=B(J,L)
        B(J,L)=B(LMAX,L)
140      B(LMAX,L)=W
        DTRMNT=-DTRMNT
C.. ZERO COLUMN J BELOW THE DIAGONAL.
150      Z(J)=1./A(J,J)
        DO 190 K=J1,N
            IF (A(K,J)) 160,190,160
160      W=-Z(J)*A(K,J)
        DO 170 L=J1,N
170      A(K,L)=W*A(J,L)+A(K,L)
        DO 180 L=1,N1
180      B(K,L)=W*B(J,L)+B(K,L)
190      CONTINUE
200  CONTINUE
        IF (A(N,N)) 210,290,210
210  Z(N)=1./A(N,N)
C.. OBTAIN SOLUTION BY BACK SUBSTITUTION.
        DO 220 L=1,N1
220  B(N,L)=Z(N)*B(N,L)
        DO 250 K=1,NM1
            J=N-K
            J1=J+1
            DO 240 L=1,N1
                W=0.
                DO 230 I=J1,N
                    W=A(J,I)*B(I,L)+W
230            B(J,L)=(B(J,L)-W)*Z(J)
240

```

```
250 CONTINUE
C.. EVALUATE DETERMINANT.
IF (DTRMNT) 260,280,260
260 DO 270 J=1,N
270 DTRMNT=DTRMNT*A(J,J)
280 LNEQF=1
      RETURN
C.. SINGULAR MATRIX, SET ERROR FLAG.
290 LNEQF=2
      DTRMNT=0.
      RETURN
C
      END
```

PROGRAM HYDREX2

PROGRAM HYDREX2

C CHARACTER\*25 OFFIL, BIFIL, COFIL  
C CHARACTER\*30 TITLE  
COMMON/HEAD/TITLE  
COMMON/IOFILE/ OFFIL, BIFIL, COFIL  
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF  
INTEGER OUTPUT, BIF, OFF, COF  
COMMON /COEFF4 / COEFF4(6, 12, 8, 25), AREAN(25, 6)  
COMMON/SHIP/ISTA, LSTA, ISWL, LSWL, TF, TA, XCG, YCG, DISPL  
COMMON /DRFT12/ DRAFT(6,2), IDRAFT  
COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)  
COMMON /U / RHO, G  
COMMON/GEOMETRY/MSTA, LPPTS(25), YOFF(25, 25), NAFT, XAFT(25),  
\* YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),  
\* ZOFF(25, 25), XFPERP, XAPERP, SHIPL, SHIPB, SHIPT,  
\* Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,  
\* XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,  
\* DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),  
\* DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT  
LOGICAL WL, ADJUST  
DATA RHO /0.00088861607142/  
DATA ERRO/1.0E-37/  
C DATA OM/ 0.000, 0.200, 0.400, 0.600, 0.800, 1.000,  
1 1.200, 1.400, 2.000, 2.400, 2.800, 9.999/  
C DATA OM/0.0, 0.0992, .1718, .243, .3137, .3842, .45469,  
\* .525, .59534, .49611, .7358, 9.999/  
\* DATA OM/0.0, 0.099, 0.2, 0.3, 0.4, 0.5, 0.6, 0.7, 0.9,  
\* 1.3, 1.6, 2.2/  
\* DATA INPUT/5/, OUTPUT/6/, BIF/1/, OFF/2/, COF/3/  
-----  
C \*\*\* 1.0 Get DATA file names and assign/open files  
C  
TYPE 902  
ACCEPT 901, BIFIL  
TYPE 903  
ACCEPT 901, OFFIL  
TYPE 904  
ACCEPT 901, COFIL  
C  
OPEN(UNIT=BIF, STATUS='OLD', FILE=BIFIL)  
OPEN(UNIT=OFF, STATUS='OLD', FILE=OFFIL)  
OPEN(UNIT=COF, STATUS='NEW', FORM='UNFORMATTED', FILE=COFIL)  
C \*\*\* 2.0 Read in data from two files  
CALL INDATA  
CLOSE(BIF)  
CLOSE(OFF)  
DO 10 J=1, 6  
DRAFT(J, 2)=DRAFT(J, 1) !Aft draft = fwd draft  
10 CONTINUE  
C \*\*\* 3.0 Float ship at indexed draft then compute added mass  
and damping coefficients using Frank Close Fit.  
DO 20 IDRAFT=1, 6  
CALL FLOAT  
CALL HYDRO  
20 CONTINUE  
C \*\*\* 4.0 Write to unformatted coefficient file containing

```

C added mass and damping coefficients for each station
C at six drafts and twelve frequencies.
C
      WRITE (COF) MSTA          !Number of Stations
      WRITE (COF) (OM(I), I=1,12)   !Frequency (rad/sec)
      WRITE (COF) (DRAFT(I,1), I=1,6) !Drafts
      DO 30 L=1,MSTA !Station index
      DO 30 K=1,6   !Draft index
      DO 30 J=1,12   !Frequency index
      WRITE(COF) (COEFF4(K,J,I,L), I=1,8)
30 CONTINUE
      WRITE (COF) ((AREAN(L,K),K=1,6),L=1,MSTA) !Section areas
      STOP

C
901 FORMAT(A)
902 FORMAT(' Name of Basic INPUT File [BIF] ? > '$)
903 FORMAT(' Name of Offset File [OFF] ? > '$)
904 FORMAT(' Name of Coefficient File [COF] ? > '$)

C
      END
      SUBROUTINE HYDRO
C
      CALCULATION OF HYDRODYNAMIC FORCE COEFFICIENTS FOR THE SHIP.
C
      COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
      INTEGER OUTPUT,BIF,OFF,COF
      COMMON/HEAD/TITLE
      CHARACTER*30 TITLE
      COMMON /COEFF4/ COEFF4(6, 12, 8, 25), AREAN(25, 6)
      COMMON/DRFT12/DRAFT(6, 2), IDRAFT
      COMMON/SHIP/ISTA, LSTA, ISWL, LSWL, TF, TA, XCG, YCG, DISPL
      COMMON /SIGMA / NK, SIGMA(24), SIGMAO, ERRO, OM(12)
      COMMON /U / RHO, G
      COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25, 25), NAFT, XAFT(25),
      *           YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
      *           ZOFF(25, 25), XFPERP, XAPERP, SHIPL, SHIPB, SHIPT,
      *           Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
      *           XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
      *           DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
      *           DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
      LOGICAL ADJUST, WL
      COMMON /          / HA1, SA1, RA1, CA1, HV1, SV1, RV1, CV1,
1           RHO2, RSIG, WN, W1, W2, ERR, XRI, YRI, EJT
1           //HAO(24), SAO(24), RAO(24), CAO(24),
1           HVO(24), SVO(24), RVO(24), CVO(24)
      REAL FA(24, 8)
      EQUIVALENCE (FA(1, 1), HAO(1))
      COMMON /          / BLOGP(20, 20), YLOGP(20, 20),
1           BLOGM(20, 20), YLOGM(20, 20)
      REAL COEFF0(8), COEFF1(8)
      EQUIVALENCE (COEFF1(1), HA1)
      DATA TPI /6.2831853072/
      NODES=NWL
      ERR=ERRO
      RHO2=RHO*2.0
      XXSTA=XXF
      XWO=XWLF
      VOL0=0.0
      VOL1=0.0
      VOLV=0.0
      WPO=0.0

```

WP1=0. 0  
WP2=0. 0  
WPT=0. 0

CR IS THE CENTER OF ROLL. ROLL IS ASSUMED TO BE ABOUT THE HORIZONTAL AXIS THROUGH THE GIVEN CENTER OF GRAVITY.  
CR=YCG-DRAFT(IDRAFT, 1)-(XFPERP-XCG)\*TAN  
STRIP CALCULATION PROCEDURE FOR EACH WET STATION..

DO 240 J=ISTA, LSTA  
XXFWD=XXSTA  
XXSTA=XOFF(J)  
IF (J. EQ. LSTA) GO TO 122  
XXAFT=XOFF(J+1)  
XW2=XXAFT  
IF (J. EQ. LSWL) XW2=XWLA  
GO TO 124  
122 XXAFT=XXA  
XW2=XWLA  
124 X1=XOFF(J)-XCG

INTEGRATE OVER WATERPLANE OF THE SHIP..

IF (J. LT. ISWL) GO TO 130  
DXFWD=XWO-XXSTA  
XWO=XXSTA  
IF (. NOT. WL(J)) GO TO 130  
DXAFT=XWO-XW2  
DX=DXFWD+DXAFT  
A=X1-DXAFT/3. 0  
B=X1+DXFWD/3. 0  
XW2=DXFWD\*B\*B+DXAFT\*A\*A+(DXFWD\*\*3+DXAFT\*\*3)/18. 0  
XW1=DXFWD\*B+DXAFT\*A  
ZW=ZWL(J)  
DZW=ZW\*DX  
WPO=WPO+DZW  
WP1=WP1+ZW\*XW1  
WP2=WP2+ZW\*XW2  
WPT=WPT+DZW\*ZW\*\*2

SET UP STATION GEOMETRY..

130 NON=INPTS(J)  
IF (NON. EQ. 0) GO TO 140  
NWL=0  
IF (WL(J)) NWL=NODES  
CALL STATN (ZOFF(1,J), Y1(1,J), ZWL(J), INPTS(J))  
IF (NON. LE. 0) GO TO 140

INTEGRATE OVER SUBMERGED VOLUME OF THE SHIP..

DXFWD=XXFWD-XXSTA  
DXAFT=XXSTA-XXAFT  
DX=(DXFWD+DXAFT)/2. 0  
VOL0=VOL0+AREA\*DX  
A=X1-DXAFT/3. 0  
B=X1+DXFWD/3. 0  
DX2=(DXFWD\*B\*B+DXAFT\*A\*A)/2. 0+(DXFWD\*\*3+DXAFT\*\*3)/36. 0  
DX1=(DXFWD\*B+DXAFT\*A)/2. 0  
VOL1=VOL1+AREA\*DX1  
VOLV=VOLV+VERT\*DX

```

C 140    CONTINUE
C      DO 150 I=1,8
C          COEFF0(I)=0.0
C 150    CONTINUE
C      CALL GIRL
C
C      DO 210 K=1,12
C          ESIG=OM(K)
C          RSIG=ESIG*RHO2
C          WN=ESIG*ESIG/G
C *** Zero (K=1) or Infinite (K=12) Frequency Computations
C     IF(K.EQ.1.OR.K.EQ.12) THEN
C         CALL BEER(K)
C     ELSE
C *** Non zero and non-infinite frequency computations
C         W1=TPI/WN
C         W2=2.0/WN
C         CALL WINE (K)
C     ENDIF
C
C-----180    CONTINUE
C
C      DO 190 I=1,8
C          COEFF4(IDRAFT,K,I,J)=COEFF1(I)/AREA
C 190    CONTINUE
C
C          AREAN(J, IDRAFT)=AREA
C          HAO(K)=HA1
C          SAO(K)=SA1
C          RAO(K)=RA1
C          CAO(K)=CA1
C          HVO(K)=HV1
C          SVO(K)=SV1
C          RVO(K)=RV1
C          CVO(K)=CV1
C 210    CONTINUE
C
C-----PRINTOUT Offset and Hydrodynamic Coefficient Info.
C
C      WRITE (OUTPUT,300) TITLE
C      WRITE(OUTPUT,301) J, XOFF(J), AREA, DRAFT(IDRAFT, 1), CR,
C                      DRAFT(IDRAFT, 2)
C      *      WRITE (OUTPUT,302)
C      WRITE (OUTPUT,310) (OM(K), HAO(K), HVO(K), SAO(K), SVO(K), RAO(K),
C 1      RVO(K), CAO(K), CVO(K), K=1,12)
C *** Offset Information
C      WRITE(OUTPUT,705)
C          WRITE(OUTPUT,706)
C      N=LPTS(J)
C      M=0
C      IF (J.LT.ISTA) GO TO 670
C      IF (J.GT.LSTA) GO TO 670
C      M=INPTS(J)
C      IF(M.NE.0)WRITE(OUTPUT,710) (YOFF(I,J), ZOFF(I,J), Y1(I,J), ZOFF
C 1      (I,J), I=1,M)

```

```

      IF (WL(J)) WRITE (OUTPUT, 720) ZWL(J)
670    M=M+1
      IF (M.LE.N) WRITE (OUTPUT, 730) (YOFF(I,J),ZOFF(I,J),I=M,N)

C   220  CONTINUE
240  CONTINUE
      GAMMA=RHO*G
      DISPL=VOL0*GAMMA

C
      WPT=WPT/3.0
      YFYTO=WPO*GAMMA
      YFZRO=WP1*GAMMA
      XWA=0.0
      IF (WPO.NE.0.0) XWA=WP1/WPO
      XCB=VOL1/VOL0
      YCB=VOLV/VOL0
      XBM=WPT/VOL0
      ZBM=(WP2-WP1*XWA)/VOL0
      XGM=XBM+YCB
      ZGM=ZBM+YCB
      XWA=XWA+XCG
      XCB=XCB+XCG
      YCB=YCB+YCG
      XMXRO=XGM*DISPL
      ZMZRO=ZGM*DISPL
      WRITE (OUTPUT, 270) TITLE
      WRITE (OUTPUT, 281) DRAFT(IDRAFT, 1), DRAFT(IDRAFT, 2)
      WRITE(OUTPUT, 290) WPO, XWA, WP1, WP2, WPT
      WRITE(OUTPUT, 291) DISPL, VOL0, XCB, YCB, VOL1, VOLV
      WRITE(OUTPUT, 292) ZBM, XBM, ZGM, XGM
      WRITE(OUTPUT, 293) XMXRO, ZMZRO, YFYTO, YFZRO
      WRITE(OUTPUT, 294) XXF, XXX
      WRITE (OUTPUT, 280) XCG, YCG

C *** OUTPUT OF NOTES
      WRITE(OUTPUT, 420)
      IF (ADJUST) WRITE(OUTPUT, 430) ZMAX, YMAX
      IF (.NOT. ADJUST) WRITE(OUTPUT, 440)
      IF (NWL.GT.0) GO TO 110
      GO TO 120
110  WRITE (OUTPUT, 460) NWL
      IF (WMAX.GT.0.0) WRITE (OUTPUT, 470) WMAX
120  CONTINUE
C
      RETURN
270  FORMAT (1H1/,81(1H=/,1X,A30,'HYDROSTATIC COEFFICIENTS'
*,T64,'PROGRAM HYDREX',//,81(1H=/))
280  FORMAT (//81(1H-)/,' NOTE: All moments are about',
*'center of gravity' //,7X,'XCG=',F11.3,'YCG=',F11.3,/)
281  FORMAT(T5,' DRAFT (fwd) =',F8.2,/,T5,' DRAFT (aft) =',F8.2/)
290  FORMAT(T10,'----- WATERPLANE -----',/
*,T10,'Area',T40,F13.2,T60,' units ',/
*,T10,'LCF',T40,F13.2,T60,' units ',/
*,T10,'1st Long. Moment',T40,E13.7,T60,' units ',/
*,T10,'2nd Long. Moment',T40,E13.7,T60,' units ',/
*,T10,'2nd Transv. Moment',T40,E13.7,T60,' units ',/)

291  FORMAT(T10,'----- VOLUME -----',/
*,T10,'Displacement',T40,F13.2,T60,' units ',/
*,T10,'Volume of Displacement',T40,E13.7,T60,' units ',/
*,T10,'LCB',T40,F13.2,T60,' units ',/
*,T10,'VCB',T40,F13.2,T60,' units ',/
*,T10,'Long. Moment',T40,E13.7,T60,' units ',/)


```

```

* T10, 'Vert. Moment           , T40, E13. 7, T60, ' units ',/')
292 FORMAT(T10, '----- METACENTRIC HEIGHTS -----',/)
* T10, 'BM (longitudinal)    , T40, F13. 2, T60, ' units ',/')
* T10, 'BM (transverse)       , T40, F13. 2, T60, ' units ',/')
* T10, 'GM (longitudinal)    , T40, F13. 2, T60, ' units ',/')
* T10, 'GM (transverse)       , T40, F13. 2, T60, ' units ',/')
293 FORMAT(T10, '-----HYDROSTATIC FORCES -----',/)
* T10, 'Roll Restoring Moment , T40, E13. 7, T60, ' units ',/')
* T10, 'Pitch Restoring Moment, T40, E13. 7, T60, ' units ',/')
* T10, 'Heave Restoring Force, T40, E13. 7, T60, ' units ',/')
* T10, 'Pitch Induced Heave Force, T40, E13. 7, T60, ' units ',/')
294 FORMAT(/, T5, ' LWL begins at ', F10. 2, '/')
*      , T5, ' LWL ends at ', F10. 2, '/')
300 FORMAT(1H1/.B1(1H=),/, 1X, A30, 'ADDED MASS/DAMPING COEFFICIENTS'
*, T66, 'PROGRAM HYDREX //, B1(1H=)')
301 FORMAT (T36, 'Station 'I2/, T36, '-----',/
* T5, ' Dist. from F.P.   , F8. 2, T50, 'Area          , F11. 3, /
* T5, ' DRAFT (fwd)     , F8. 2, T50, 'Roll Ctr abv WL', F11. 3/
* T5, ' DRAFT (aft)      , F8. 2, '/')
302 FORMAT(10X, '-----HEAVE----',
*4X, '-----SWAY----', 4X, '-----ROLL----',
*4X, '--SWAY-ROLL--', /, 14X, 'A22', 5X, 'B22',
*7X, 'A33', 5X, 'B33', 8X, 'A44', 6X, 'B44', 6X, 'A34', 6X, 'B34', /
*, 2X, 'Freq. ')
309 FORMAT ((1X, OFP22. 4, 3(5X, 1P2E10. 2)))
310 FORMAT(1X, F5. 2, 3X, F8. 4, F8. 4, 2X, F8. 4, F8. 4,
*           2X, F9. 2, F9. 2, F9. 1, F9. 1)
C
420 FORMAT (1H1/, 33(1H*), ' N O T E S ', 33(1H*))
430 FORMAT(T5, 'Generate additional offset points. ',/
*      T5, 'Maximum segment height= ', F10. 3, /
*      T5, 'Maximum segment width = ', F10. 3/)
440 FORMAT(/T5, 'Use segments as defined by table of offsets.')
450 FORMAT(T5, 'No internal free-surface segments are used.')
460 FORMAT(T5, I3, 2X, 'nodes for internal free-surface.')
470 FORMAT(5X, 'Add internal nodes if surface segment lengths',
*' exceed', F10. 3)
706 FORMAT (6X, 'Height above', 5X, 'Half', 15X,
*' Submerged Offsets', /, 10X, 'Baseline', 5X, 'BREADth',
*14X, '-Y-', 9X, '-Z-')
705 FORMAT (////, 33(1H-), 'STATION OFFSETS', 32(1H-), /)
710 FORMAT (6X, 2F12. 3, F18. 3, F12. 3)
720 FORMAT (39X, 9HWATERLINE, F12. 3)
730 FORMAT (6X, 2F12. 3)
END
SUBROUTINE INDATA
C
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON /SIGMA/ NK, SIGMA(24), SIGMAO, ERRO, OM(12)
COMMON /DRFT12/ DRFT12/ DRAFT(6,2), IDRAFT
COMMON/IOFILE/ OFFIL, BIFIL, COFIL
COMMON/HEAD/TITLE
CHARACTER*30 TITLE
COMMON/U          / RHO, G
COMMON/SHIP/ISTA, LSTA, ISWL, LSWL, TF, TA, XCG, YCG, DISPL
COMMON/GEOOMETRY/MSTA, LPTS(25), YOFF(25,25), NAFT, XAFT(25),
*           YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*           ZOFF(25,25), XPERP, XAPERP, SHIPL, SHIPB, SHIPT,
*           Y1(21,25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*           XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,

```

```

*           DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*           DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
*           LOGICAL ADJUST, WL
C
C           CHARACTER*81 CARDID
C           DATA DEGREE/0.01745 32925 19943/
C           DATA G /32.17/
C           DATA NWL/1/
C
C           WRITE(OUTPUT, 197)
C *** TITLE
C           READ (BIF, 199) TITLE
C           WRITE(OUTPUT, 196) TITLE
C *** DRAFT (fwd), DRAFT (aft), long. loc's of DRAFT marks
C           READ (BIF, 200) TF, TA, XFPERP, XAPERP
C           WRITE(OUTPUT, 200) TF, TA, XFPERP, XAPERP
C *** Center of Gravity (XCG aft of FP, YCG above BL)
C           READ (BIF, 200) XCG, YCG, ZCG
C           WRITE(OUTPUT, 200) XCG, YCG, ZCG
C *** Six DRAFTs at which hydro. coeffs are computed
C           READ(BIF, 200) (DRAFT(I,1), I=1,6)
C           WRITE(OUTPUT, 200) (DRAFT(I,1), I=1,6)
C *** Minimum segment lengths for Frank Close Fit
C           READ (BIF, 201) YMAX, ZMAX, WMAX, NWL
C           WRITE(OUTPUT, 201) YMAX, ZMAX, WMAX, NWL
C           ADJUST=ZMAX. GT. 0.0 AND. YMAX. GT. 0.0
C *** Number of forward profile points
C           READ (BIF, 190) NFWD
C           WRITE(OUTPUT, 190) NFWD
C           IF (NFWD. GT. 25) CALL ERROR(15, IDUM, RDUM)
C *** Coordinates of forward profile points
C           IF (NFWD. GT. 0) READ (BIF, 430) (YFWD(I), XFWD(I), I=1, NFWD)
C           WRITE(OUTPUT, 430) (YFWD(I), XFWD(I), I=1, NFWD)
C *** Number of aft profile points
C           READ (BIF, 190) NAFT
C           WRITE(OUTPUT, 190) NAFT
C           IF (NAFT. GT. 25) CALL ERROR(16, IDUM, RDUM)
C *** Coordinates of aft profile points
C           IF (NAFT. GT. 0) READ (BIF, 430) (YAFT(I), XAFT(I), I=1, NAFT)
C           WRITE(OUTPUT, 430) (YAFT(I), XAFT(I), I=1, NAFT)
C
C
C-----
```

C

C Section 2.0 - READ OFFSET file

C The offset file can be an actual SHCP DATA File

C

C WRITE(OUTPUT, 198)

C \*\*\* CARD TYPE A

C READ (OFF, 410) CARDID

C WRITE(OUTPUT, 410) CARDID

C \*\*\* CARD TYPE B

C READ (OFF, 410)

C \*\*\* CARD TYPE C

C READ (OFF, 412) SPACE, ZSCAL, YSCAL, SHIPL, NAPN, KINDO

C WRITE(OUTPUT, 412) SPACE, ZSCAL, YSCAL, SHIPL, NAPN, KINDO

C IF (SPACE. EQ. 0.0) SPACE=1.0

C ZSCAL=1.0

C YSCAL=1.0

C MSTAB=0

```

NFWD=0
NAFT=0
C
C *** CARD TYPE D
30 N=1
MSTA=MSTA+1
IF (MSTA.GT.25) CALL ERROR(10, IDUM, RDUM)
READ (OFF, 416) STATNO,Y11,Z1,JTEST
WRITE(OUTPUT,417) STATNO,Y11,Z1,JTEST
XOFF(MSTA)=STATNO*SPACE
GO TO 50
40 CONTINUE           !loop within each station
N=N+1
IF (N.GT.25) CALL ERROR(11, MSTA, RDUM)
READ (OFF, 416) S, Y11, Z1, JTEST
WRITE(OUTPUT,417) S, Y11, Z1, JTEST
IF (S.NE. STATNO) CALL ERROR(12, MSTA, RDUM)
50 YOFF(N,MSTA)=Z1*ZSCAL
ZDFF(N,MSTA)=Y11*YSCAL
IF (JTEST.EQ.0 .OR. JTEST.EQ. 77777) GO TO 40
LPTS(MSTA)=N          !No. of points- MSTA
IF (N.LT.2) CALL ERROR(13, MSTA, RDUM)
IF (JTEST.EQ.88888) GO TO 30      !Go onto next station
IF (JTEST.NE.99999) CALL ERROR(14, JTEST, RDUM)
C
C
DO 220 J=1, MSTA
XOFF(J)=-XOFF(J)
220 CONTINUE
IF (NFWD.EQ.0) GO TO 240
X=XOFF(1)
DO 230 I=1, NFWD
XFWD(I)=XFWD(I)+X
230 CONTINUE
240 CONTINUE
X=XOFF(MSTA)
DO 250 I=1, NAFT
XAFT(I)=X-XAFT(I)
250 CONTINUE
RETURN
180 FORMAT (5X, I5)
190 FORMAT (I5)
197 FORMAT(1H1/, 81(1H*)//, ' INPUT DATA ECHO ', T64,
*'PROGRAM HYDREX'//, 81(1H*)//, 33(1H-),
*[B] [F] DATA FILE', 32(1H-)//)
198 FORMAT(1H1/, 81(1H*)//, ' INPUT DATA ECHO ', T64,
*'PROGRAM HYDREX'//, 81(1H*)//, 33(1H-),
*[OFF] DATA FILE', 32(1H-)//)
196 FORMAT(1X, A)
199 FORMAT(A)
200 FORMAT (6F10.2)
201 FORMAT (3F10.2, I5)
210 FORMAT (F10.2, I5, 5X, F10.2)
C
410 FORMAT (A)
412 FORMAT (4F10.3, 13X, I2, 4X, I1)
414 FORMAT (5X, I5, 5X, 'INPUT OF SHCP (YPE D OFFSET DATA')
416 FORMAT (F6.3, 2F7.0, I6)
417 FORMAT (F7.3, 2F10.2, I6)
420 FORMAT (2I5, F10.2)
430 FORMAT (2F10.2)

```

```

C
C      END
C      SUBROUTINE INSERT(A1,A2,J1,L1,L2)
C      Purpose: Inserts array A2 into array A1 at location J1.
C      REAL A1(1), A2(1)
C      IF (L1.LT.J1) GO TO 120
C      M=L1+L2
C      I=L1
C      K=L1-J1+1
C      DO 110 J=1,K
C          A1(M)=A1(I)
C          M=M-1
C          I=I-1
C 110 CONTINUE
C 120 I=J1-1
C      DO 130 K=1,L2
C          M=K+I
C          A1(M)=A2(K)
C 130 CONTINUE
C      RETURN
C      END
C      SUBROUTINE STATN (Z, Y, ZW, NPTS)
```

CALCULATION OF DATA CONCERNING STATION GEOMETRY.  
 REVISION OF OFFSETS FOR GOOD RESULTS MAY BE PERFORMED.

NON = NUMBER OF CALCULATED MIDPOINTS.  
 NWL = NUMBER OF WATERLINE MIDPOINTS.  
 Z = HORIZONTAL COORDINATE OF SEGMENT ENDPOINT.  
 Y = VERTICAL COORDINATE OF SEGMENT ENDPOINT.  
 ZZ = HORIZONTAL COORDINATE OF SEGMENT MIDPOINT.  
 YY = VERTICAL COORDINATE OF SEGMENT MIDPOINT.  
 SNE = HORIZONTAL COMPONENT OF UNIT NORMAL TO SEGMENT.  
 CSE = VERTICAL COMPONENT OF UNIT NORMAL.  
 DEL = LENGTH OF SEGMENT.  
 ROL = MOMENT OF JUNIT NORMAL ABOUT CENTER OF ROLL (CG).

```

REAL Y(1), Z(1)
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25, 25), NAFT, XAFT(25),
*           YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*           ZOFF(25, 25), XFFERP, XAPERP, SHIPB, SHIPT,
*           Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*           XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
*           DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*           DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
COMMON ,           / HA1, SA1, RA1, CA1, HV1, SV1, RV1, CV1,
1           RHO2, RSIG, WN, W1, W2, ERR, XRI, YRI, EJT
COMMON /           / HAO(24), SAO(24), RAO(24), CAO(24),
1           HVO(24), SVO(24), RVO(24), CVO(24)
COMMON // ZNEW(20), YNEW(20), ZZNEW(20), YYNEW(20), CNEW(20), SNEW(20),
1 DNEW(20), RNEW(20), MORE(20), I, K, Z0, Y0, M1, MTOT, ZINT, YINT, NUMBER, M, N1
2, I1, JOB, ZS, YS, D, C, S, P, Q, NUT
LOGICAL ADJUST
DATA LIM1T/20/
DATA MAXPTS/20/
AREA=0.0
VERT=0.0
ZO=0.0
YO=Y(1)
```

```

MTOT=0
K=1
I1=K
IF (Z(1), EQ, 0, 0) I1=2
IF (I1, GT, NPTS) GO TO 130
C
C CALCULATION LOOP FOR SUBMERGED OFFSET POINTS..
C
DO 120 I=I1,NPTS
ZINT=Z(I)-ZO
YINT=Y(I)-YO
D=SQRT(ZINT*ZINT+YINT*YINT)
IF (D, EQ, 0, 0) GO TO 120
IF (.NOT. ADJUST) GO TO 110
C
C CODE INSTRUCTIONS FOR THE ADDITION OF POINTS..
C
NUMBER=MAX0(IABS(IFIX(ZINT/ZMAX)), IABS(IFIX(YINT/YMAX)))
MORE(K)=NUMBER
MTOT=MTOT+NUMBER
C
C CONTINUE STANDARD PROCEDURE..
C
110 ZS=ZO+Z(I)
YS=YO+Y(I)
AREA=AREA+YINT*ZS
VERT=VERT+YINT*(ZO*(YO-CR+YINT/3.0)+Z(I)*(YO-CR+YINT/1.5))
C=ZINT/D
S=YINT/D
CSE(K)=C
SNE(K)=S
DEL(K)=D
ZZ(K)=0.5*ZS
YY(K)=0.5*YS
ROL(K)=(CR-YY(K))*S-ZZ(K)*C
Z2(K)=ZO
Y2(K)=YO
ZO=Z(I)
YO=Y(I)
K=K+1
120 CONTINUE
C
C END OF CALCULATION LOOP FOR SUBMERGED POINTS.
C
130 Z2(K)=ZO
Y2(K)=YO
NON=K-1
C
C ADD UPPERMOST SEGMENT..
C
IF (NWL, NE, 0) GO TO 150
SECTION IS SUBMERGED.
IF (ZO, EQ, 0, 0) GO TO 200
IF (.NOT. ADJUST) GO TO 140
C
C CODE INSTRUCTIONS FOR THE ADDITION OF POINTS..
C
NUMBER=IABS(IFIX(ZO/ZMAX))
MORE(K)=NUMBER
MTOT=MTOT+NUMBER
C

```

```

C      CONTINUE STANDARD PROCEDURE. .
C
140  DEL(K)=ABS(ZO)
     CSE(K)=-1.0
     SNE(K)=0.0
     ZZ(K)=0.5*ZO
     YY(K)=YO
     ROL(K)=ZZ(K)
     NON=K
     K=K+1
     Z2(K)=0.0
     Y2(K)=YO
     GO TO 200
C
C      ADD SEGMENT UP TO WATERLINE. .
C
150  ZINT=ZW-ZO
     YINT=-YO
     IF (NWL.LT.0) NWL=0
     IF (ZW.LE.0.0) NWL=0
     D=SQRT(ZINT*ZINT+YINT*YINT)
     IF (D.EQ.0.0) GO TO 170
     IF (.NOT.ADJUST) GO TO 160
C
C      CODE INSTRUCTIONS FOR THE ADDITION OF POINTS. .
C
     NUMBER=MAX0(IABS(IFIX(ZINT/ZMAX)), IABS(IFIX(YINT/YMAX)))
     MORE(K)=NUMBER
     MTOT=MTOT+NUMBER
C
C      CONTINUE STANDARD PROCEDURE. .
C
160  ZS=ZO+ZW
     YS=YO
     AREA=AREA+YINT*ZS
     VERT=VERT-YINT*(ZO*(CR+YINT/1.5)+ZW*(CR+YINT/3.0))
     C=ZINT/D
     S=YINT/D
     CSE(K)=C
     SNE(K)=S
     DEL(K)=D
     ZZ(K)=0.5*ZS
     YY(K)=0.5*YS
     ROL(K)=(CR-YY(K))*S-ZZ(K)*C
     NON=K
     K=K+1
     Z2(K)=ZW
     Y2(K)=0.0
C
C      ADD DECK AT WATERLINE. .
C
170  CONTINUE
     IF (NWL.EQ.0) GO TO 200
     ZINT=ZW/FLOAT(NWL)
     IF (WMAX.EQ.0.0) GO TO 180
     IF (ZINT.LT.WMAX) GO TO 180
     NWL=IFIX(ZW/WMAX)+1
     ZINT=ZW/FLOAT(NWL)
180  D=ZINT*0.5
     DO 190 I=1,NWL
         DEL(K)=ZINT

```

```

C
      SUBROUTINE POTST
      COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
*     ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
*     STOLD(120), PX(120,6)
      COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150), WRFR(150),
*     KK(150,4)
      COMMON/A/NPAN, NPT, GEE, RHO, NKX, NKY, EYE, DT, TIM, UFWD
      COMPLEX A, B, EYE
      DIMENSION XPSL(3,4), XPSLR(3,4), PBB(120,120)
      COMMON/PTST/ARE4(200,4), X4(200,4), Y4(200,4), Z4(200,4)
*     , SEL(200,4)
      DO 1500 J=1, NPAN
      ARE4(J,4)=-1.0
      JT=4
      IF(KK(J,4).EQ.0) JT=3
      DO 1500 JJ=1, JT
      J2=1
      IF(JJ.LT.JT) J2=JJ+1
      KF=KK(J,JJ)
      KG=KK(J,J2)
      X4(J,JJ)=(XPT(KF)+XPT(KG)+XPAN(J))/3.0
      Y4(J,JJ)=(YPT(KF)+YPT(KG)+YPAN(J))/3.0
      Z4(J,JJ)=(ZPT(KF)+ZPT(KG)+ZPAN(J))/3.0
      AF=XPT(KF)-XPAN(J)
      BF=YPT(KF)-YPAN(J)
      CF=ZPT(KF)-ZPAN(J)
      AG=XPT(KG)-XPAN(J)
      BG=YPT(KG)-YPAN(J)
      CG=ZPT(KG)-ZPAN(J)
      CALL SELF(AF,BF,CF,AG,BG,CG,FEE)
      SEL(J,JJ)=FEE
      CR=AF*BG-BF*AG
      AR=BF*CG-CF*BG
      BR=CF*AG-AF*CG
      ARE4(J,JJ)=0.5*SQRT(AR*AR+BR*BR+CR*CR)
1500    CONTINUE
      DO 127 NJ=1, NPAN
      DO 1277 MJ=1, NPAN
      PBB(NJ,MJ)=0.00
      P(NJ,1)=0.00
      P(NJ,2)=0.00
      P(NJ,3)=0.00
      P(NJ,4)=0.00
      P(NJ,5)=0.00
      P(NJ,6)=0.00
      DO 128 NK=1, 4
      ARN=ARE4(NJ,NK)
      IF(ARN.LT.0.0) GO TO 128
      P1=0.0
      P2=0.0
      P3=0.0
      P4=0.0
      P5=0.0
      P6=0.0
      X=X4(NJ,NK)
      Y=Y4(NJ,NK)
      Z=Z4(NJ,NK)
      DO 138 MJ=1, NPAN
      DO 138 MK=1, 4
      XF=X4(MJ,MK)
      YF=Y4(MJ,MK)
      ZF=Z4(MJ,MK)
      ARM=ARE4(MJ,MK)
      IF(ARM.LT.0.00) GO TO 138
      IF(NJ.NE.MJ) GO TO 140
      IF(MK.NE.NK) GO TO 140
      FRA=SEL(MJ,MK)/ARM
      GO TO 1380

```

```

CSE(K)=-1.0
SNE(K)=0.0
YY(K)=0.0
ZZ(K)=Z2(K)-D
ROL(K)=ZZ(K)
NON=K
K=K+1
Y2(K)=0.0
Z2(K)=Z2(K-1)-ZINT
190 CONTINUE
Z2(K)=0.0
NON=K-1
C      END OF FIRST PASS.  ADD ADDITIONAL SEGMENTS IF REQUIRED..
C
200 IF (NON.GT.LIMIT) GO TO 290
IF (.NOT.ADJUST) GO TO 280
IF (NON.GT.MAXPTS) GO TO 280
IF (MTOT.EQ.0) GO TO 280
MTOT=M1CT+NON
M1=NON-NWL
IF (MTOT.LE.MAXPTS) GO TO 230
C      DECREASE MORE UNTIL MTOT IS EQUAL MAXPTS ..
C
210 DO 220 K=1,M1
IF (MORE(K).LE.0) GO TO 220
MORE(K)=MORE(K)-1
MTOT=MTOT-1
IF (MTOT.LE.MAXPTS) GO TO 230
220 CONTINUE
GO TO 210
C      INSERT ADDITIONAL SEGMENTS AS INDICATED BY MORE ..
C
230 I=1
DO 270 M=1,M1
I1=I+1
NUMBER=MORE(M)
IF (NUMBER.LE.0) GO TO 260
N1=NUMBER+1
Z0=Z2(I)
YO=Y2(I)
ZINT=Z2(I1)-Z0
YINT=Y2(I1)-YO
ZINT=ZINT/FLOAT(2*N1)
YINT=YINT/FLOAT(2*N1)
D=DEL(I)/FLOAT(N1)
C=CSE(I)
S=SNE(I)
DO 240 K=1,N1
P=(K-1)*2
Q=P+1.0
ZNEW(K)=Z0+P*ZINT
YNEW(K)=YO+P*YINT
ZZNEW(K)=Z0+Q*ZINT
YYNEW(K)=YO+Q*YINT
RNEW(K)=(CR-YYNEW(K))*S-ZZNEW(K)*C
240 CONTINUE
DO 250 K=1,NUMBER
DNEW(K)=D

```

```

      CNEW(K)=C
250   SNEW(K)=S
      ZZ(I)=ZZNEW(N1)
      YY(I)=YYNEW(N1)
      ROL(I)=RNEW(N1)
      DEL(I)=D
      NUT=NON+1
      CALL INSERT (Z2, ZNEW(2), I1, NUT, NUMBER)
      CALL INSERT (Y2, YNEW(2), I1, NUT, NUMBER)
      CALL INSERT (ZZ, ZZNEW, I, NON, NUMBER)
      CALL INSERT (YY, YYNEW, I, NON, NUMBER)
      CALL INSERT (DEL, DNEW, I, NON, NUMBER)
      CALL INSERT (ROL, RNEW, I, NON, NUMBER)
      CALL INSERT (CSE, CNEW, I, NON, NUMBER)
      CALL INSERT (SNE, SNEW, I, NON, NUMBER)

260   I=I1+NUMBER
      NON=NON+NUMBER
270   CONTINUE
280   NOE=NON+NON
C
C     RETURN
C
C     ERROR DIAGNOSTICS..
C
C     TOO MANY WET SEGMENTS..
C
290   WRITE (OUTPUT, 300) XXSTA
      STOP 7
C
300   FORMAT(' More than 20 wet segments for station at X=',F13.5)
C
C     END
C     SUBROUTINE FLOAT
C
C     THIS SUBROUTINE APPLIES THE GIVEN DRAFT TO THE ORIGINAL TABLE
C     OF OFFSETS.
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
C
COMMON/SHIP/ISTA, LSTA, ISWL, LSWL, TF, TA, XCG, YCG, DISPL
COMMON/DRFT12/ DRAFT(6,2), IDRAFT
COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25,25), NAFT, XAFT(25),
*          YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*          ZOFF(25,25), XFFERP, XAPERP, SHIPL, SHIPB, SHIPT,
*          Y1(21,25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*          XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
*          DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*          DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
LOGICAL WL, ADJUST
C
C     PLACE SHIP AT GIVEN DRAFT..
C-----
C-----  

C     TF=DRAFT(IDRAFT, 1)
C     TA=DRAFT(IDRAFT, 2)
C-----  

C-----  

C     IF (XFPERP. NE. XAPERP) GO TO 130

```

```

XFPERP=XOFF(1)
XAPERP=XOFF(MSTA)
IF (XFPERP, NE, XAPERP) GO TO 130
TAN=0.0
IF (TF, EQ, TA) GO TO 140
WRITE (OUTPUT, 570) XFFERP, TF, TA
STOP 5
130 TAN=(TA-TF)/(XFPERP-XAPERP)
140 ISTA=0
ISWL=0
LSWL=0
XX=XOFF(1)
DO 190 J=1, MSTA
IF (XX, GE, XOFF(J)) GO TO 142
WRITE (OUTPUT, 575) J, XOFF(J), XX
STOP 6
C      TJ IS DRAFT OF STATION J.
C
142  XX=XOFF(J)
TJ=(XFPERP-XX)*TAN+TF
YNEXT=YOFF(1,J)-TJ
N=0
IF (YNEXT, GT, 0.0) GO TO 152
LSTA=J
IF (ISTA, EQ, 0) ISTA=J
Y1(1,J)=YNEXT
N=LPTS(J)
DO 150 I=2, N
YNEXT=YOFF(I,J)-TJ
IF (YNEXT, GT, 0.0) GO TO 160
Y1(I,J)=YNEXT
150  CONTINUE
I=N+1
IF (YNEXT, EQ, 0.0) GO TO 170
C      SECTION IS NOT SURFACE PIERCING..
C
152  INPTS(J)=N
WL(J)=.FALSE.
GO TO 190
C      SECTION IS SURFACE PIERCING. FIND WATERLINE COORDINATES..
C
160  YO=YOFF(I-1,J)-TJ
IF (YO, EQ, 0.0) GO TO 170
INPTS(J)=I-1
ZO=ZOFF(I-1,J)
ZWL(J)=ZO-YO*(ZOFF(I,J)-ZO)/(YNEXT-YO)
GO TO 180
C
170  INPTS(J)=I-2
ZWL(J)=ZOFF(I-1,J)
C
180  WL(J)=.TRUE.
LSWL=J
IF (ISWL, EQ, 0) ISWL=J
190  CONTINUE
IF (ISTA, NE, 0) GO TO 200
WRITE (OUTPUT, 580)
STOP 77

```

```

C FIND FORWARD AND AFTER ENDS OF WETTED HULL. .
C
200 XWLA=1, 0E32
XWLF=-XWLA
IF (ISWL, EQ. 0) GO TO 210
XWLF=XOFF (ISWL)
XWLA=XOFF (LSWL)
210 XXF=XOFF (ISTA)
IF (NFWD, EQ. 0) GO TO 250
IF (NFWD, GT. 1) GO TO 220
C XFWD(1) DEFINED AS FORWARD END OF WATERLINE. .
C
XWLF=AMAX1 (XFWD(1), XWLF)
XXF=AMAX1 (XWLF, XXF)
GO TO 250
C FIND FORWARD END OF WATERLINE AND FORWARD END OF WETTED HULL. .
C
220 YO=(XFWD(1)-XFPERP)*TAN+YFWD(1)-TF
DO 230 J=2, NFWD
XX=XFWD(J)
YNEXT=(XX-XFPERP)*TAN+YFWD(J)-TF
IF (YNEXT, LT. 0, 0) GO TO 228
IF (YO, GT. 0, 0) GO TO 229
IF (YNEXT, EQ. 0, 0) GO TO 227
C INTERPOLATE FOR WATERLINE. .
C
XO=XFWD(J-1)
XX=(XX-XO)/(YO-YNEXT)*YO+XO
227 IF (XX, LE. XWLF) GO TO 229
XWLF=XX
C
228 XXF=AMAX1 (XX, XXF)
229 YO=YNEXT
230 CONTINUE
C FIND AFTER END OF WATERLINE AND AFTER END OF WETTED HULL. .
C
250 XXX=XOFF (LSTA)
IF (NAFT, EQ. 0) GO TO 290
IF (NAFT, GT. 1) GO TO 260
C XAFT(1) DEFINED AS AFTER END OF WATER LINE. .
C
XWLA=AMIN1 (XAFT(1), XWLA)
XXA=AMIN1 (XWLA, XXX)
GO TO 290
C FIND AFTER END OF WATERLINE AND AFTER END OF WETTED HULL. .
C
260 YO=(XAFT(1)-XFPERP)*TAN+YAFT(1)-TF
DO 270 J=2, NAFT
XX=XAFT(J)
YNEXT=(XX-XFPERP)*TAN+YAFT(J)-TF
IF (YNEXT, LT. 0, 0) GO TO 268
IF (YO, GT. 0, 0) GO TO 268
IF (YNEXT, EQ. 0, 0) GO TO 267
C

```

```

C      INTERPOLATE FOR WATERLINE..
C
C      XO=XAFT(J-1)
C      XX=(XX-XO)/(YO-YNEXT)*YO+XO
267      IF (XX.GE.XWLA) GO TO 269
C      XWLA=XX
C
268      XXA=AMIN1(XX,XXA)
269      YO=YNEXT
270      CONTINUE
290      IF (ISWL.EQ.0) ISWL=26
C
420      FORMAT (32H0S T A T I O N   G E O M E T R Y)
480      FORMAT (22HO    DRAFT FWD (AT X =,F10.3,3H) =,F10.3/5X,17HDRAFT AF
1T (AT X =,F10.3,3H) =,F10.3)
570      FORMAT (61H0*** TWO DRAFTS SPECIFIED, AND LENGTH BETWEEN PERPS. IS
1 ZERO. /31H *** BOTH PERPENDICULARS AT X =,F12.4/16H *** DRAFT FWD
2=,F12.4/16H *** DRAFT AFT =,F12.4)
575      FORMAT (12H0*** STATION, I3,5H (X =,F12.4,18H) IS OUT OF ORDER. /29H
1 *** PREVIOUS STATION HAS X =,F12.4)
580      FORMAT (25H0*** SHIP IS ABOVE WATER. )
C
C      END
C      SUBROUTINE ERROR(NO, IDUM, RDUM)
C      COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
C      INTEGER OUTPUT, BIF, OFF, COF
C      WRITE(OUTPUT, 10) NO
C      WRITE(OUTPUT, 11) IDUM, RDUM
10      FORMAT(' STOPPED DUE TO ERROR NO. ', I2, //)
11      FORMAT(1X, I3, 5X, F10.3)
C      STOP
C      END
C      SUBROUTINE BEER (K)
C
C1      TWO-DIMENSIONAL HYDRODYNAMIC CALCULATION FOR THE SPECIAL CASE
C1      OF ZERO OR INFINITE FREQUENCY.
C1
C5      COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25,25), NAFT, XAFT(25),
*          YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*          ZOFF(25,25), XPERP, XAPERP, SHIPL, SHIPB, SHIPT,
*          Y1(21,25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*          XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
*          DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*          DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
C      COMMON // HAH, SAS, RAR, CCA, HVH, SVS, RVR, CCV, RH02, RSIG, WN, W1, W2, ERR, Z
1RI, YRI, EJT
C      COMMON /      HAO(24,8), BLOGP(20,20), YLOGP(20,20), BLOGM(20
1,20), YLOGM(20,20), CONH(40), CONR(40,2), CROLL(40,40), CHEAV(40,40), HE
2AVI(20,20), HEAVT(20,20), ROLLI(20,20), ROLLT(20,20), EJI, CZRI, CZLI, SZ
3RI, SZLI, RARI, RALI, RBRI, RBLI, CLI, CRI, SLI, SRI, I, IPESO, J, NJ
C5      INPUT AND OUTPUT LOGICAL UNITS.
C5      COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
C5      INTEGER OUTPUT, BIF, OFF, COF
C5
C5      OUTPUT LISTING PAGE HEADING DATA..
C5
C5      HAH=0.0
C5      SAS=0.0
C5      RAR=0.0

```

```

CCA=0.0
HVH=0.0
SVS=0.0
RVR=0.0
CCV=0.0
NN=NON-NWL
C3
C-----  

C
C3      IF (WN, NE, 0.) GO TO 130
C3      ZERO FREQUENCY CASE..
C3
DO 120 I=1, NN
  XM1=ZZ(I)-Z2(1)
  XP1=ZZ(I)+Z2(1)
  YP1=YY(I)+Y2(1)
  FCR1=.5*ALOG(XM1**2+YP1**2)
  FCL1=.5*ALOG(XP1**2+YP1**2)
  ACR1=ATAN2(YP1, XM1)
  ACL1=ATAN2(YP1, XP1)
  DO 110 J=1, NN
    XM2=ZZ(I)-Z2(J+1)
    XP2=ZZ(I)+Z2(J+1)
    YP2=YY(I)+Y2(J+1)
    FCR2=.5*ALOG(XM2**2+YP2**2)
    FCL2=.5*ALOG(XP2**2+YP2**2)
    ACR2=ATAN2(YP2, XM2)
    ACL2=ATAN2(YP2, XP2)
    SIMJ=SNE(I)*CSE(J)-SNE(J)*CSE(I)
    CIMJ=CSE(I)*CSE(J)+SNE(I)*SNE(J)
    SIPJ=SNE(I)*CSE(J)+SNE(J)*CSE(I)
    CIPJ=CSE(I)*CSE(J)-SNE(I)*SNE(J)
    DCNR=SIPJ*(FCR1-FCR2)+CIPJ*(ACR1-ACR2)
    PCR=CSE((I)*(XM1*FCR1-YP1*ACR1-XM1-XM2*FCR2+YP2*ACR2+XM2)+SNE
    (J)*(YP2*FCR2+XM2*ACR2+YP1-YP1*FCR1-XM1*ACR1-YP2))
    DCNL=CIMJ*(FCL2-FCL1)+CIMJ*(ACL2-ACL1)
    PCL=CPL(J)*(XP2*FCL2-YP2*ACL2-XP2-XP1*FCL1+YP1*ACL1+XP1)+SNE
    (J)*(YP2*FCL2+XP2*ACL2-YP2-YP1*FCL1-XP1*ACL1+YP1)
    CROLL(I, J)=BLOGM(J, I)+2.0*(DCNR-DCNL)
    CHEAV(I, J)=BLOGP(J, I)+2.0*(DCNR+DCNL)
    ROLLT(I, J)=-YLOGM(J, I)-2.0*(PCR-PCL)
    HEAVT(I, J)=-YLOGP(J, I)-2.0*(PCR+PCL)
    IF (J, EQ, NN) GO TO 110
    XM1=XM2
    XP1=XP2
    YP1=YP2
    FCR1=FCR2
    FCL1=FCL2
    ACR1=ACR2
    ACL1=ACL2
110  CONTINUE
120  CONTINUE
GO TO 160
C3
C3      INFINITE FREQUENCY CASE..
C3
130  CONTINUE
DO 150 I=1, NN
  DO 140 J=1, NN
    CROLL(I, J)=BLOGM(J, I)
    CHEAV(I, J)=BLOGP(J, I)

```

```

        ROLLT(I, J)=-YLOGM(J, I)
        HEAVT(I, J)=-YLOGP(J, I)
140    CONTINUE
150    CONTINUE
C3
C3    SOLUTION FOR EITHER THE ZERO OR INFINITE FREQUENCY CASE..
C3
160    CONTINUE
      DO 170 I=1, NN
          CONH(I)=CSE(I)
          CONR(I, 1)=-SNE(I)
          CONR(I, 2)=ROL(I)
170    CONTINUE
      IT=LNEGT(40, NN, 1, CHEAV, CONH, ERR, HEAVI)
      IF (IT.EQ.0) GO TO 180
      IF (WN.EQ.0.0) WRITE (OUTPUT, 230)
      IF (WN.NE.0.0) WRITE (OUTPUT, 240)
      WRITE (OUTPUT, 270) XXSTA
      IF (IT.NE.0) GO TO 190
180    CONTINUE
      IT=LNEGT(40, NN, 2, CROLL, CONR, ERR, ROLLI)
      IF (IT.EQ.0) GO TO 200
      IF (WN.EQ.0.0) WRITE (OUTPUT, 250)
      IF (WN.NE.0.0) WRITE (OUTPUT, 260)
      WRITE (OUTPUT, 270) XXSTA
      IF (IT.EQ.1) GO TO 200
190    WRITE (OUTPUT, 280)
      STOP 10
C3
C3    EVALUATE VELOCITY POTENTIALS AND FORCE COEFFICIENTS..
C3
200    DO 220 I=1, NN
        PAH=0.0
        PAS=0.0
        PAR=0.0
        DO 210 J=1, NN
            PAH=PAH+CONH(J)*HEAVT(J, I)
            PAS=PAS+CONR(J, 1)*ROLLT(J, I)
            PAR=PAR+CONR(J, 2)*ROLLT(J, I)
210    CONTINUE
C6
C6    THE PRESSURES IN PHASE WITH THE SINUSOIDAL DISPLACEMENT ARE..
C6
C6    HEAVE -- PAH = PAH*RHO*ESIG*ESIG
C6    SWAY -- PAS = PAS*RHO*ESIG*ESIG
C6    ROLL -- PAR = PAR*RHO*ESIG*ESIG
C6
C6    THE ACCELERATION COMPONENTS OF THE FORCE ARE EQUAL
C6    IN MAGNITUDE TO THE ABOVE, BUT HAVE THE OPPOSITE SIGN.
C6
        DDD=DEL(I)
        DCI=CSE(I)*DDD
        DSI=-SNE(I)*DDD
        DFR=ROL(I)*DDD
C6
C6    INTEGRATION TO OBTAIN FORCE ACCELERATION COEFFICIENTS..
C6
        HAH=HAH+PAH*DCI
        SAS=SAS+PAS*DSI
        RAR=RAR+PAR*DFR
        CCA=PAR*DSI+PAS*DFR+CCA

```

```

C6
220 CONTINUE
    HAH=HAH*RHO2
    SAS=SAS*RHO2
    RAR=RAR*RHO2
    CCA=CCA*RHO2/2.0
    IF(WN, EQ. 0.) HAH=99. ! INFINITE AT ZERO FREQ
    RETURN

C
230 FORMAT (43H *** HEAVE MATRIX, ZERO ENCOUNTER FREQUENCY)
240 FORMAT (37H *** HEAVE MATRIX, INFINITE FREQUENCY)
250 FORMAT (47H *** SWAY-ROLL MATRIX, ZERO ENCOUNTER FREQUENCY)
260 FORMAT (41H *** SWAY-ROLL MATRIX, INFINITE FREQUENCY)
270 FORMAT (31H *** COEFFS. FOR STATION AT X =,F13.5)
280 FORMAT (26H *** EXECUTION TERMINATED. )

C
END
SUBROUTINE GIRL

C1
C1 CALCULATION OF FREQUENCY INDEPENDENT TERMS TO BE USED IN THE
C1 TWO-DIMENSIONAL HYDRODYNAMIC CALCULATIONS.

C1
C6 THIS SUBROUTINE IS CALLED ONCE FOR EACH STATION OF THE SHIP
C6 WHEN THE HYDRODYNAMIC COEFFICIENTS ARE BEING GENERATED.
C6
C5
COMMON/GEOOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*           YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*           ZOFF(25,25),XFFERP,XAPERP,SHIPB,SHIPT,
*           Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*           XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*           DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*           DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
COMMON // HA1,SA1,RA1,CA1,HV1,SV1,RV1,CV1,RHO2,RSIG,WN,W1,W2,ERR,Z
1RI,YRI,EJT
COMMON /      HAO(24,8),BLOGP(20,20),YLOGP(20,20),BLDMG(20,
120),YLGM(20,20),I,J,ACLI,ACLT,ACRI,ACRT,APLI,APLT,APRI,APRT,CIMJ,
2CIPJ,DCNL,DCNR,DPNL,FCLI,FCLT,FCRI,FCRT,FPLI,FPLT,FPRI,FPRT,P
3CL,PCR,PPL,PPR,SIMJ,SIPJ,ZMI,ZMT,ZPI,ZPT,YMI,YMT,YPI,YPT
DATA PIN/-3.14159265358979/
DATA TPI/6.28318530717958/
DO 150 I=1,NON
    ZMI=ZZ(I)
    ZPI=ZMI
    YMI=YY(I)-Y2(1)
    YPI=YY(I)+Y2(1)
    FPRI= ALOG(ZMI*ZMI+YMI*YMI)/2.0
    FPLI=FPRI
    FCRI= ALOG(ZMI*ZMI+YPI*YPI)/2.0
    FCLI=FCRJ
    APRI=ATAN2(YMI,ZMI)
    APLI=APRI
    ACRI=ATAN2(YPI,ZMI)
    ACLI=ACRI
    DO 150 J=1,NON
        J1=J+1
        YMT=YY(I)-Y2(J1)
        YPT=YY(I)+Y2(J1)
        ZMT=ZZ(I)-Z2(J1)
        ZPT=ZZ(I)+Z2(J1)
C       CALCULATE ANGLES (MEASURED OUTSIDE SECTION)..
```

```

APRT=ATAN2(YMT, ZMT)
IF (ZMT, GE, 0, 0) GO TO 130
IF (J1, GT, I) GO TO 110
IF (YMT, LT, 0, 0) APRT=APRT+TPI
GO TO 120
110 IF (YMT, GE, 0, 0) APRT=APRT-TPI
IF (YPT, LT, 0, 0) GO TO 130
ACRT=PIN
GO TO 140
130 ACRT=ATAN2(YPT, ZMT)
140 ACLT=ATAN2(YPT, ZPT)
APLT=ATAN2(YMT, ZPT)
FPRT=ALOG(ZMT*ZMT+YMT*YMT)/2.0
FPLT=ALOG(ZPT*ZPT+YMT*YMT)/2.0
FCRT=ALOG(ZMT*ZMT+YPT*YPT)/2.0
FCLT=ALOG(ZPT*ZPT+YPT*YPT)/2.0
SIMJ=SNE(I)*CSE(J)-SNE(J)*CSE(I)
CIMJ=CSE(I)*CSE(J)+SNE(I)*SNE(J)
SIPJ=SNE(I)*CSE(J)+SNE(J)*CSE(I)
CIPJ=CSE(I)*CSE(J)-SNE(I)*SNE(J)
DPNR=SIMJ*(FPRI-FPRT)+CIMJ*(APRI-APRT)
PPR=CSE(J)*(ZMI*FPRI-YMI*APRI-ZMI-ZMT*FPRT+YMT*APRT+ZMT)+SNE
(J)*(YMI*FPRI+ZMI*APRI-YMI-YMT*FPRT-ZMT*APRT+YMT)
1 DPNL=SIPJ*(FPLT-FPLI)+CIPJ*(APLT-APLI)
PPL=CSE(J)*(ZPT*FPLT-YMT*APLT-ZPT-ZPI*FPLI+YMI*APLI+ZPI)+SNE
(J)*(YMI*FPLI+ZPI*APLI+YMT-YMT*FPLT-ZPT*APLT-YMI)
DCNR=SIPJ*(FCRI-FCRT)+CIPJ*(ACRI-ACRT)
PCR=CSE(J)*(ZMI*FCRI-YPI*ACRI-ZMI-ZMT*FCRT+YPT*ACRT+ZMT)+SNE
(J)*(YPT*FCRT+ZMT*ACRT+YPI-YPI*FCRI-ZMI*ACRI-YPT)
DCNL=SIMJ*(FCLT-FCLI)+CIMJ*(ACLT-ACLI)
PCL=CSE(J)*(ZPT*FCLT-YPT*ACLT-ZPT-ZPI*FCLI+YPI*ACLI+ZPI)+SNE
(J)*(YPT*FCLT+ZPT*ACLT-YPT-YPI*FCLI-ZPI*ACLI+YPI)
BLOGP(J, I)=DPNR+DPNL-DCNR-DCNL
YLOGP(J, I)=PPR+PPL-PCR-PCL
BLOGM(J, I)=DPNR-DPNL-DCNR+DCNL
YLOGM(J, I)=PPR-PPL-PCR+PCL
IF (J, EQ, NON) GO TO 150
FPRI=FPRT
FPLI=FPLT
FCRI=FCRT
FCLI=FCLT
APRI=APRT
APLI=APLT
ACRI=ACRT
ACLI=ACLT
ZMI=ZMT
YMI=YMT
ZPI=ZPT
YPI=YPT
150 CONTINUE
160 CONTINUE
RETURN
C
END
SUBROUTINE WINE (K)
C
C1 TWO-DIMENSIONAL HYDRODYNAMIC CALCULATION FOR NON-ZERO FREQUENCIES.
C2
C3 THIS SUBROUTINE IS CALLED FOR EACH STATION AND ALL NON-ZERO
C4 FREQUENCIES WHEN THE HYDRODYNAMIC COEFFICIENTS ARE BEING
C5 GENERATED.
C6

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```

C6
C5
C5 INPUT AND OUTPUT LOGICAL UNITS.
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
C5
C5
COMMON/GEOOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
* YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
* ZOFF(25,25),XPERP,XAPERP,SHIPB,SHIPT,
* Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
* XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
* DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
* DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
COMMON //,HAH,SAS,RAR,CCA,HVH,SVS,RVR,CCV,RHO2,RSIG,WN,W1,W2,ERR,Z
1RI,YRI,EJT
COMMON /      /,HAO(24,8),BLOGP(20,20),YLOGP(20,20),BLOGM(20
1,20),YLOGM(20,20),CONH(40),CONR(40,2),CROLL(40,40),CHEAV(40,40),HE
2AVI(20,20),HEAVT(20,20),ROLLI(20,20),ROLLT(20,20),EJI,CZRI,CZLI,SZ
3RI,SZLI,RARI,PALI,RBRI,RBLI,CLI,CRI,SLI,SRI,I,IPES0,NI
DO 110 I=1,NON
    NI=NON+I
    CONH(I)=0.0
    CONR(I,1)=0.0
    CONR(I,2)=0.0
    CONH(NI)=CSE(I)
    CONR(NI,1)=-SNE(I)
    CONR(NI,2)=ROL(I)
    ZRI=WN*ZZ(I)
    YRI=-WN*(YY(I)+Y2(1))
    EJT=EXP(-YRI)
    EJI=EJT
    CALL ROMEO (CZRI,SZRI,RARI,RBRI,CRI,SRI)
    CZLI=CZRI
    SZLI=SZRI
    RALI=RARI
    RBLI=RBRI
    CLI=CRI
    SLI=SRI
    CALL WOMEN (I,BLOGP(1,I),YLOGP(1,I),BLOGM(1,I),YLOGM(1,I),CHEAV
1,(1,I),CROLL(1,I),HEAVI(1,I),HEAVT(1,I),ROLLI(1,I),ROLLT(1,I))
110 CONTINUE
    IF (NWL.EQ.0) GO TO 130
    I=NOE-NWL+1
    DO 120 I=I,NOE
        CONH(I)=0.0
        CONR(I,1)=0.0
        CONR(I,2)=0.0
120 CONTINUE
130 IT=JULIET(1,CHEAV,CONH)
    IF (IT.EQ.0) GO TO 140
    WRITE (OUTPUT,180) K,WN,XXSTA
    IF (IT.NE.1) GO TO 150
140 IT=JULIET(2,CROLL,CONR)
    IF (IT.EQ.0) GO TO 160
    WRITE (OUTPUT,190) K,WN,XXSTA
    IF (IT.EQ.1) GO TO 160
150 WRITE (OUTPUT,200)
    STOP 11
C
160 HAH=0.0

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```

SAS=0. 0
RAR=0. 0
CCA=0. 0
HVH=0. 0
SVS=0. 0
RVR=0. 0
CCV=0. 0
C9 SLIGHT INCREASE IN SPEED IF THE FINAL INTEGRATION AVOIDS THE
C9 INTERIOR SURFACE SEGMENTS..
C9 NI = NON - NWL
C9 DO *** I=1,NI
C9
C9 DO 170 I=1,NON
C9     CALL SONG (HEAVI(1,I),HEAVT(1,I),ROLLI(1,I),ROLLT(1,I),I)
170 CONTINUE
C6 FORCE COEFFICIENTS.
C6 FORCE IS THAT WHICH MUST BE APPLIED TO THE CYLINDER (PER UNIT
C6 LENGTH) TO CAUSE SINUSOIDAL OSCILLATIONS AT THE GIVEN FREQUENCY
C6 AND UNIT AMPLITUDE.
C6 COEFFICIENTS ARE THE PARTIAL DERIVATIVES OF THE FORCE BY THE
C6 ACCELERATION OR VELOCITY COMPONENT OF THE GIVEN MOTION.
C6
C6 ACCELERATION TERMS. .
C6
C6 HAH=HAH*RHO2
C6 SAS=SAS*RHO2
C6 RAR=RAR*RHO2
C6 CCA=CCA*RHO2/2. 0
C6
C6 VELOCITY TERMS. .
C6
C6 HVH=HVH*RSIG
C6 SVS=SVS*RSIG
C6 RVR=RVR*RSIG
C6 CCV=CCV*RSIG/2. 0
C6
C6 RETURN
C3
180 FORMAT (36H *** HEAVE MATRIX, FREQUENCY INDEX =, I3, 15H, WAVE NUMBE
1R =, 1PE13. 5/31H *** COEFFS. FOR STATION AT X =, 0PF13. 5)
190 FORMAT (40H *** SWAY-ROLL MATRIX, FREQUENCY INDEX =, I3, 15H, WAVE N
1NUMBER =, 1PE13. 5/31H *** COEFFS. FOR STATION AT X =, 0PF13. 5)
200 FORMAT (26H *** EXECUTION TERMINATED.)
C
C END
C SUBROUTINE WOMEN
1      (I,BLOGP,YLOGP,BLOGM,YLOGM,CHI,CRI,HII,HTI,RII,RTI)
C
C      REAL BLOGP(1),BLOGM(1),YLOGP(1),YLOGM(1),CHI(1),HII(1),RII(1),CRI(
11),HTI(1),RTI(1)
C5
COMMON/GEOOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*           YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*           ZOFF(25,25),XPERP,XAPERP,SHIPL,SIPB,SHIPT,
*           Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*           XXA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*           DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*           DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
*           COMMON // HA1,SA1,RA1,CA1,HV1,SV1,RV1,CV1,RHO2,RSIG,WN,W1,UU,ERR,X

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```

1RT, YRT, EJT
COMMON /          HAO(24, 8), BP(20, 20), YP(20, 20), BM(20, 20), YM(2
10, 20), CONH(40), CONR(40, 2), CROLL(40, 40), CHEAV(40, 40), HEAVI(20, 20), H
2EAVT(20, 20), ROLLI(20, 20), ROLLT(20, 20), EJI, CZRI, CZLI, SZRI, SZLI, RARI
3, RALI, RBRI, RBLI, CLI, CRQ, SLI, SRI
DATA TPI/6.28318530717958/
YYI=YY(I)
ZZI=ZZ(I)
SI=SNE(I)
CI=CSE(I)
DO 110 J=1, NON
XRT=WN*(ZZI-ZZ(J+1))
YRT=-WN*(YYI+Y2(J+1))
EJT=EXP(-YRT)
CALL ROMEO (CZRT, SZRT, RART, RBRT, CRT, SRT)
XRT=WN*(ZZI+ZZ(J+1))
CALL ROMEO (CZLT, SZLT, RALT, RBLT, CLT, SLT)
CJ=CSE(J)
SJ=SNE(J)
SSS=SI*CJ
TTT=SJ*CI
UUU=CI*CJ
VVV=SI*SJ
CIPJ=UUU-VVV
SIPJ=SSS+TTT
SIMJ=SSS-TTT
CIMJ=UUU+VVV
SSS=SIMJ*(CLI-CLT)-CIMJ*(SLI-SLT)
TTT=SIPJ*(CRG-CRT)-CIPJ*(SRI-SRT)
UUU=SJ*(RALI-RALT)+CJ*(RBLT-RBLI)
VVV=SJ*(RARI-RART)+CJ*(RBRI-RBRT)
WWW=EJT*(SZRT*CIPJ-CZRT*SIPJ)-EJI*(SZRI*CIPJ-CZRI*SIPJ)
RRR=EJT*(SZLT*CIMJ-CZLT*SIMJ)-EJI*(SZLI*CIMJ-CZLI*SIMJ)
QQQ=EJI*(SZRI*CJ-CZRI*SJ)-EJT*(SZRT*CJ-CZRT*SJ)
PPP=EJI*(SZLI*CJ+CZLI*SJ)-EJT*(SZLT*CJ+CZLT*SJ)
CHI(J)=BLOGP(J)+2.0*(TTT-SSS)
CRI(J)=BLOGM(J)+2.0*(TTT+SSS)
HII(J)=YLOGP(J)+UU*(VVV+UUU)
RII(J)=YLOGM(J)+UU*(VVV-UUU)
CHN(NJ) = CHI(J)
CRN(NJ) = CRI(J)
NJ=NON+J
CHI(NJ)=TPI*(WWW-RRR)
CRI(NJ)=TPI*(WWW+RRR)
HTI(J)=W1*(QQQ-PPP)
RTI(J)=W1*(QQQ+PPP)
CHN(J) = -CHI(NJ)
CRN(J) = -CRI(NJ)
IF (J, EQ, NON) GO TO 110
EJI=EJT
CRQ=CRT
SRI=SRT
CLI=CLT
SLI=SLT
RARI=RART
RBRI=RBRT
RALI=RALT
RBLI=RBLT
CZRI=CZRT
SZRI=SZRT
CZLI=CZLT

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      SZLI=SZLT
110 CONTINUE
      RETURN
C
      END
      SUBROUTINE SONG (HAI, HOT, RAI, ROT, I)
C
      DIMENSION HAI(1), HOT(1), RAI(1), ROT(1), PP(6)
C5
      COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25, 25), NAFT, XAFT(25),
*          YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
*          ZOFF(25, 25), XPERP, XAPERP, SHIPL, SHIPB, SHIPT,
*          Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
*          XXA, TAN, NON, NOE, NWL, CR, XXFWD, XXSTA, XXAFT, DX, DX1,
*          DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
*          DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
      COMMON // HAH, SAS, RAR, CCA, HVH, SVS, RVR, CCV, RH02, RSIG, WN, W1, W2, ERR, Z
1RI, YRI, EJT
      COMMON /           / HAO(24, 8), BLOGP(20, 20), YLOGP(20, 20), BLOGM(20
1, 20), YLOGM(20, 20), CONH(40), CONR(40, 2)
      PAH=0.0
      PAS=0.0
      PAR=0.0
      PVH=0.0
      PVS=0.0
      PVR=0.0
      DO 110 J=1, NON
      NJ=NON+J
      PAH=PAH+CONH(J)*HOT(J)-CONH(NJ)*HAI(J)
      PAS=PAS+CONR(J, 1)*ROT(J)-CONR(NJ, 1)*RAI(J)
      PAR=PAR+CONR(J, 2)*ROT(J)-CONR(NJ, 2)*RAI(J)
      PVH=PVH+CONH(J)*HAI(J)+CONH(NJ)*HOT(J)
      PVS=PVS+CONR(J, 1)*RAI(J)+CONR(NJ, 1)*ROT(J)
      PVR=PVR+CONR(J, 2)*RAI(J)+CONR(NJ, 2)*ROT(J)
110 CONTINUE
      DDD=DEL(I)
      DCI=CSE(I)*DDD
      DSI=-SNE(I)*DDD
      DFR=ROL(I)*DDD
C6
      C6 THE PRESSURES ON THIS SEGMENT OF THE CYLINDER MAY BE CALCULATED.
C6
      C6 THE PRESSURES IN PHASE WITH THE SINUSOIDAL DISPLACEMENT ARE..
C6
      C6 HEAVE -- PAH = PAH*RHO*ESIG*ESIG
      C6 SWAY -- PAS = PAS*RHO*ESIG*ESIG
      C6 ROLL -- PAR = PAR*RHO*ESIG*ESIG
C6
      C6 OF COURSE THE ACCELERATION COMPONENTS OF THE FORCE ARE EQUAL
      C6 IN MAGNITUDE TO THE ABOVE, BUT HAVE THE OPPOSITE SIGN.
C6
      C6 THE PRESSURES IN PHASE WITH THE SINUSOIDAL VELOCITY ARE..
C6
      C6 HEAVE -- PVH = PVH*RHO*ESIG*ESIG
      C6 SWAY -- PVS = PVS*RHO*ESIG*ESIG
      C6 ROLL -- PVR = PVR*RHO*ESIG*ESIG
C6
      C6 INTEGRATION TO OBTAIN FORCE ACCELERATION COEFFICIENTS. .
      HAH=HAH+PAH*DCI

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SAS=SAS+PAS*DSI
RAR=RAR+PAR*DFR
C6
CCA=PAR*DSI+PAS*DFR+CCA
C6 INTEGRATION TO OBTAIN FORCE VELOCITY COEFFICIENTS. .
C6
HVH=HVH+PVH*DCI
SVS=SVS+PVS*DSI
RVR=RVR+PVR*DFR
CCV=PVR*DSI+PVS*DFR+CCV
C6
C6 AT THIS POINT THE PRESSURES REQUIRE THE MODIFICATIONS NOTED
C6 ABOVE TO GIVE THE DIMENSIONAL VALUES.
C6 THE INTEGRATIONS OF THE PRESSURES ARE COMPLETED ELSEWHERE
C6 IN THE PROGRAM TO GIVE DIMENSIONAL FORCE COEFFICIENTS.
C6
RETURN
C
END
SUBROUTINE ROMEO (C, S, RA, RB, CIN, SON)
C
C1 EXPONENTIAL INTEGRAL WITH COMPLEX ARGUMENT.
C2
C2 THE ARGUMENT IS SUPPLIED THROUGH BLANK COMMON AS THE VARIABLES
C2 X AND Y.
C3
C3 PARAMETERS AND VARIABLES. .
C3 X -- REAL PART OF ARGUMENT
C3 Y -- IMAGINARY PART OF ARGUMENT
C3 E -- EXP( -Y )
C3 C -- COS( X )
C3 S -- SIN( X )
C3 CIN -- REAL RESULT
C3 SON -- IMAGINARY RESULT
C3 RA -- ALOG( X**2 + Y**2 )/2.0 - CIN
C3 RB -- ATAN( X/Y ) - PI/2.0 + SON
C3
C5
COMMON/GEOMETRY/MSTA, LPTS(25), YOFF(25, 25), NAFT, XAFT(25),
* YAFT(25), NFWD, XFWD(25), YFWD(25), XOFF(25),
* ZOFF(25, 25), XFPERP, XAPERP, SHIPL, SHIPB, SHIPT,
* Y1(21, 25), ZWL(25), WL(25), INPTS(25), XWLF, XWLA, XXF,
* XXA, TAN, NON, NOE, NWL, CR, XXFWD, XSTA, XXAFT, DX, DX1,
* DX2, Z2(21), Y2(21), ZZ(20), YY(20), SNE(20), CSE(20),
* DEL(20), ROL(20), ADJUST, WMAX, YMAX, ZMAX, AREA, VERT
* COMMON / HA1, SA1, RA1, CA1, HV1, SV1, RV1, CV1,
1 RHO2, RSIG, WN, W1, W2, ERR, X, Y, E
C5
C5 INPUT AND OUTPUT LOGICAL UNITS.
COMMON/IO/INPUT, OUTPUT, BIF, OFF, COF
INTEGER OUTPUT, BIF, OFF, COF
DATA GAMMA /0.5772 15664 90153 28606 06512/
DATA HALFPI/1.5707 96326 79489 66192 31322/
C
AT=ATAN2(X, Y)
ARG=AT-HALFPI
C=COS(X)
S=SIN(X)
R=X*X+Y*Y
AL=0.5*ALOG(R)
TEST=0.00001

```

```

IF (R.LT.1.) GO TO 130
TEST=.1*TEST
IF (R.LT.2.) GO TO 130
TEST=.1*TEST
IF (R.LT.4.) GO TO 130
TEST=.1*TEST
130 SUMC=GAMMA+AL+Y
SUMS=AT+X
TC=Y
TS=X
COX=1.
DO 140 K=2, 501
   TO=TC
   FACT=COX/FLOAT(K)**2
   COX=K
   TC=FACT*(Y*TC-X*TS)
   TS=FACT*(Y*TS+X*TO)
   SUMC=SUMC+TC
   SUMS=SUMS+TS
   IF ((ABS(TC)+ABS(TS)).LE. TEST) GO TO 150
140 CONTINUE
WRITE (OUTPUT,190) XXSTA,X,Y,WN
STOP 12
150 CIN=E*(C*SUMC+S*SUMS)
SON=E*(S*SUMC-C*SUMS)
RA=AL-CIN
RB=ARG+SON
RETURN
C
190 FORMAT (59H0*** NON-CONVERGENT EXPONENTIAL INTEGRAL FOR STATION AT
1 X =,F13.5/22H *** PARAMETERS -- X =,1PE13.5,5H, Y =,E13.3,15H, WA
2VE NUMBER =,E13.5)
C
END
FUNCTION JULIET (N1,A,B)
C
C. SOLVES SIMULTANEOUS LINEAR EQUATIONS BY GAUSSIAN REDUCTION.
C. FOR THE SPECIALIZED MATRICES IN THE SUBROUTINE WINE.
C
REAL A(40,1),B(40,1)
C2
C2 THE A MATRIX MUST BE DIMENSIONED WITH EXACTLY 40 ROWS AND
C2 AT LEAST 40 COLUMNS. THE B MATRIX MUST ALSO BE DIMENSIONED
C2 WITH EXACTLY 40 ROWS AND AT LEAST N1 COLUMNS.
C2
C5
C5 INPUT AND OUTPUT LOGICAL UNITS.
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
C5
C5
COMMON/GEOMETRY/MSTA,LPTS(25),YOFF(25,25),NAFT,XAFT(25),
*      YAFT(25),NFWD,XFWD(25),YFWD(25),XOFF(25),
*      ZOFF(25,25),XFPERP,XAPERP,SHIPL,SHIPB,SHIPT,
*      Y1(21,25),ZWL(25),WL(25),INPTS(25),XWLF,XWLA,XXF,
*      XA,TAN,NON,NOE,NWL,CR,XXFWD,XXSTA,XXAFT,DX,DX1,
*      DX2,Z2(21),Y2(21),ZZ(20),YY(20),SNE(20),CSE(20),
*      DEL(20),ROL(20),ADJUST,WMAX,YMAX,ZMAX,AREA,VERT
COMMON // HA1,SA1,RA1,CA1,HV1,SV1,RV1,CV1,RHO2,RSIG,WN,W1,W2,ERR,Z
1RI,YRI,EJT
C

```

```

C
COMMON /          HAO(24,8), BLOGP(20,20,4), CONH(40,3), CROLL(40,
1, 40, 2), HEAVI(20, 20, 4), EJI, CZRI, CZLI, SZRI, SZLI, RARI, RALI, RBRI, RBLI,
2CLI, CRQ, SLI, SRI, Z(40)
C
N2=NOE/2
D=1.0
C.. COMPLETE THE MATRIX A.
C
DO 120 J=1, N2
L=N2+J
DO 110 I=1, N2
K=N2+I
A(I,L)=-A(K,J)
A(K,L)=A(I,J)
110 CONTINUE
120 CONTINUE
C
NM1=NOE-1
C.. SOLVE AT*X=B FOR X , WHERE AT IS THE TRANPOSE OF THE
C MATRIX A . STORE THE X VECTOR(S) IN B .
C
DO 210 J=1, NM1
J1=J+1
C.. FIND ELEMENT OF ROW J, COLS J--N, WHICH HAS MAX ABSOLUTE VALUE.
C
LMAX=J
RMAX=ABS(A(J,J))
DO 130 K=J1, NOE
RNEXT=ABS(A(J,K))
IF (RMAX.GE. RNEXT) GO TO 130
RMAX=RNEXT
LMAX=K
130 CONTINUE
IF (LMAX.NE. J) GO TO 140
C.. MAX ELEMENT IS ON DIAGONAL.
C
IF (A(J,J)) 170, 260, 170
C.. MAX ELEMENT IS NOT ON DIAGONAL.
C.. EXCHANGE COLUMNS J AND LMAX.
C
140 DO 150 L=J, NOE
W=A(L,J)
A(L,J)=A(L,LMAX)
A(L,LMAX)=W
150 CONTINUE
C.. EXCHANGE ROWS J AND LMAX.
C
DO 160 L=1, N1
W=B(J,L)
B(J,L)=B(LMAX,L)
B(LMAX,L)=W
160 CONTINUE
D=-D
C

```

```

C.. ZERO ROW J TO RIGHT OF DIAGONAL.
C
170      D=A(J,J)*D
          V=1.0/A(J,J)
          Z(J)=V
          DO 200 K=J1,NOE
              IF (A(J,K).EQ.0.0) GO TO 200
              W=-V*A(J,K)
              DO 180 L=J1,NOE
                  A(L,K)=W*A(L,J)+A(L,K)
180      CONTINUE
          DO 190 L=1,N1
              B(K,L)=W*B(J,L)+B(K,L)
190      CONTINUE
200      CONTINUE
210      CONTINUE
          D=A(NOE,NOE)*D
          IF (A(NOE,NOE).EQ.0.0) GO TO 260
          Z(NOE)=1.0/A(NOE,NOE)

C.. OBTAIN SOLUTION BY BACK SUBSTITUTION.
C
        DO 220 L=1,N1
            B(NOE,L)=Z(NOE)*B(NOE,L)
220      CONTINUE
        DO 250 K=1,NM1
            J=NOE-K
            J1=J+1
            DO 240 L=1,N1
                W=0.0
                DO 230 I=J1,NOE
                    W=A(I,J)*B(I,L)+W
230            CONTINUE
                B(J,L)=(B(J,L)-W)*Z(J)
240      CONTINUE
250      CONTINUE
        IF (ABS(D).LT.ERR) GO TO 270
C
        JULIET=0
C.. NO PROBLEMS DURING THIS EXECUTION.
C
        RETURN
C.. SINGULAR MATRIX--MAXIMUM ELEMENT IN ROW IS ZERO.
C
260    JULIET=3
        WRITE (OUTPUT,280)
        RETURN
C.. ABSOLUTE DETERMINANT VALUE LESS THAN ERROR VALUE. .
C
270    JULIET=1
        WRITE (OUTPUT,290) D,ERR
        RETURN
C
280    FORMAT (20H0*** SINGULAR MATRIX)
290    FORMAT (18H0*** DETERMINANT =,1PE13.5,24H,  ERROR SPECIFICATION =,
1E13.5)
C
        END

```

```

FUNCTION LNEQT(M, N, N1, A, B, ERROR , Z)
C. . SOLVES SIMULTANEOUS LINEAR EQUATIONS BY GAUSSIAN REDUCTION.
C. . SOLVES A*X=B FOR X , AND STORES THE X VECTOR(S) IN B
C. . REAL A(M, M), B(M, M) , Z(M), ERROR , RMAX, RNEXT, W
C. .
C5 INPUT AND OUTPUT LOGICAL UNITS.
COMMON/IO/INPUT,OUTPUT,BIF,OFF,COF
INTEGER OUTPUT,BIF,OFF,COF
C5
C D=1. 0
NM1=N-1
IF (NM1. EQ. 0) GO TO 210
DO 200 J=1,NM1
J1=J+1
C. . FIND ELEMENT OF COL J, ROWS J-N, WHICH HAS MAX ABSOLUTE VALUE.
C
LMAX=J
RMAX=ABS(A(J, J))
DO 110 K=J1, N
    RNEXT=ABS(A(K, J))
    IF (RMAX. GE. RNEXT) GO TO 110
    RMAX=RNEXT
    LMAX=K
110    CONTINUE
    IF (LMAX. NE. J) GO TO 120
C. . MAX ELEMENT IN COLUMN IS ON DIAGONAL
C
    IF (A(J, J)) 150, 270, 150
C. . MAX ELEMENT IS NOT ON DIAGONAL. EXCHANGE ROWS J AND LMAX.
C
120    DO 130 L=J, N
        W=A(J, L)
        A(J, L)=A(LMAX, L)
        A(LMAX, L)=W
130    CONTINUE
    DO 140 L=1, N1
        W=B(J, L)
        B(J, L)=B(LMAX, L)
        B(LMAX, L)=W
140    CONTINUE
D=-D
C. . ZERO COLUMN J BELOW THE DIAGONAL.
C
150    D=A(J, J)*D
    Z(J)=1. 0/A(J, J)
    DO 190 K=J1, N
        IF (A(K, J)) 160, 190, 160
160        W=-Z(J)*A(K, J)
        DO 170 L=J1, N
            A(K, L)=W*A(J, L)+A(K, L)
170    CONTINUE
    DO 180 L=1, N1
        B(K, L)=W*B(J, L)+B(K, L)

```

```

180      CONTINUE
190      CONTINUE
200      CONTINUE
210 D=A(N,N)*D
      IF (A(N,N).EQ.0.0) GO TO 270
      Z(N)=1./A(N,N)

C.. OBTAIN SOLUTION BY BACK SUBSTITUTION.
C
      DO 220 L=1,N1
         B(N,L)=Z(N)*B(N,L)
220 CONTINUE
      IF (NM1.EQ.0) GO TO 260
      DO 250 K=1,NM1
         J=N-K
         J1=J+1
         DO 240 L=1,N1
            W=0.
            DO 230 I=J1,N
               W=A(J,I)*B(I,L)+W
230         CONTINUE
               B(J,L)=(B(J,L)-W)*Z(J)
240     CONTINUE
250 CONTINUE
260 LNEQT=0
      IF (ABS(D).GE.ERROR) RETURN
      LNEQT=1
      WRITE (OUTPUT,280) D,ERROR
      RETURN

C.. SINGULAR MATRIX--MAXIMUM ELEMENT IN COLUMN IS ZERO.
C
      270 LNEQT=3
      WRITE (OUTPUT,290)
      RETURN

C
      280 FORMAT (1BH0*** DETERMINANT =,1PE13.5,24H,  ERROR SPECIFICATION =,
      1E13.5)
      290 FORMAT (20H0*** SINGULAR MATRIX)
C
      END

```

PROGRAM HYDREX3

PROGRAM HYDREX3

```
C CHARACTER*25 PANFIL, MATFIL
      COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120),
*   ST(120), ACN(120), ACNW(120), AN(120,3), E(120), P(120,6),
*   PRFS(120), STOLD(120), PX(120,6)
*   COMMON/FS/AKZ(100, 100), SS(100, 100), CC(100, 100),
*   DKX(100), DKY(100), AKX(100), AKY(100)
*   COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150),
*   WRFR(150), KK(150, 4)
      COMMON/A/NPAN, NPT, GEE, RHO, NKX, NKY, EYE, DT, TIM, UFWD
      DIMENSION PF(6), PB(6), PT(6)
      COMMON/WAVEX/OMEGA
      COMMON/BP/BPRES(120), TPRES(120)
      COMPLEX EYE
      EYE=(0.0, 1.0)

C-----
      TYPE 1
      ACCEPT 4, PANFIL
      TYPE 2
      ACCEPT 4, MATFIL
      OPEN(UNIT=2, FILE=PANFIL, TYPE='OLD')
      OPEN(UNIT=3, FILE=MATFIL, FORM='UNFORMATTED', TYPE='NEW')
      OPEN(UNIT=99, FILE='X.DAT', FORM='UNFORMATTED', TYPE='NEW')
      CALL EBD
      CALL POTST
      WRITE(6,6)
      WRITE(6,7) J, AN(J,1), AN(J,2), AN(J,3),
*           XPAN(J), YPAN(J), ZPAN(J), AREA(J)
150    CONTINUE
      STOP
1      FORMAT(' Input name of [PAN] file >$')
2      FORMAT(' Input name of [MAT] file >$')
4      FORMAT(A)
6      FORMAT('J', 9X, 'NX', 9X, 'NY', 9X, 'NZ', 9X, 'XP', 9X,
*           'YP', 9X, 'ZP', 9X, 'AREA')
7      FORMAT(1X, I5, 7F11.4)
      END
```

```

SUBROUTINE PREP(J)
COMMON/BD/XPAN(120),YPAN(120),ZFPAN(120),AREA(120),ST(120),
* ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
* STOLD(120),PX(120,6)
COMMON/BD2/XPT(150),YPT(150),ZPT(150),WRF(150),WRFR(150),
* KK(150,4)
COMMON/ARE/RR(500),XZJ(200),YXJ(200),ZYJ(200)
ZYT=0.0
YXT=0.00
XZT=0.00
J4=J*4
JT=4
IF(KK(J,4).EQ.0) JT=3
DO 20 JJ=1, JT
J4=J4+1
J2=1
IF(JJ.LT.JT) J2=JJ+1
KF=KK(J,J2)
KG=KK(J,J2)
AG=XPT(KG)
BG=YPT(KG)
CG=ZPT(KG)
AF=XPT(KF)
BF=YPT(KF)
CF=ZPT(KF)
R=SQRT((AF-AG)**2+(BF-BG)**2+(CF-CG)**2)
XT=AF-XPAN(J)
YT=BF-YPAN(J)
ZT=CF-ZPAN(J)
ANX=(AF-AG)/R
ANY=(BF-BG)/R
ANZ=(CF-CG)/R
DOT=ANX*XT+ANY*YT+ANZ*ZT
XT=XT-DOT*ANX
YT=YT-DOT*ANY
ZT=ZT-DOT*ANZ
ZYT=ZYT+ZT*ANY-ANZ*YT
YXT=YXT+YT*ANX-ANY*XT
XZT=XZT+XT*ANZ-ANX*ZT
RR(J4)=R
CONTINUE
XZJ(J)=SIGN(AN(J,2), XZT)
YXJ(J)=SIGN(AN(J,3), YXT)
ZYJ(J)=SIGN(AN(J,1), ZYT)
RETURN
END
20
```

```

SUBROUTINE SELF(AF,BF,CF,AG,BG,CG,FEE)
REAL LB21,LA21
ASQ=AF*AF+BF*BF+CF*CF
BSQ=AG*AG+BG*BG+CG*CG
ADB=AF*AG+BF*BG+CF*CG
ADB2=ADB+ADB
ASAS=(AF*BG-BF*AG)**2+(CF*BG-BF*CG)**2+(AF*CG-BF*AG)**2
FF=0.00
DO 15 MK=1, 10
DO 15 NK=1, MK
LA21=FLOAT(NK-MK)
A2SQ=ASQ*LA21*LA21
DO 15 ML=1, 11-MK
DO 15 NL=1, 11-ML
LB21=FLOAT(NL-ML)
IF(LA21.NE.0.) GO TO 5
IF(LB21.LT.0.) GO TO 5
GO TO 15
5   R=SQRT(A2SQ+ABD2*LA21*LB21+BSQ*LB21*LB21)
FF=FF+1.0/R
CONTINUE
FEE=FF*ASAS*0.002
RETURN
END
15
```

```

SUBROUTINE SOLID(XPN, G, NSIDE)
DIMENSION CS(4), SN(4), Z(4), XPN(3, 4)
G=-6. 2B3185308
ACR12=XPN(1, 1)*XPN(1, 2)+XPN(2, 1)*XPN(2, 2)+XPN(2, 2)*XPN(3, 2)
ACR13=XPN(1, 1)*XPN(1, 3)+XPN(2, 1)*XPN(2, 3)+XPN(3, 1)*XPN(3, 3)
ACR23=XPN(1, 2)*XPN(1, 3)+XPN(2, 2)*XPN(2, 3)+XPN(3, 2)*XPN(3, 3)
IF(NSIDE.EQ.4) GO TO 40
G=-3. 141592659
CS(1)=ACR23-ACR13*ACR12
CS(2)=ACR13-ACR12*ACR23
CS(3)=ACR12-ACR23*ACR13
SN(1)=XPN(1, 1)*(XPN(2, 2)*XPN(3, 3)-XPN(3, 2)*XPN(2, 3))+  

+ XPN(2, 1)*(XPN(3, 2)*XPN(1, 3)-XPN(1, 2)*XPN(3, 3))+  

+ XPN(3, 1)*(XPN(1, 2)*XPN(2, 3)-XPN(2, 2)*XPN(1, 3))
SN(2)=SN(1)
SN(3)=SN(1)
SN(4)=0.
GO TO 50
40 ACR14=XPN(1, 1)*XPN(1, 4)+XPN(2, 1)*XPN(2, 4)+XPN(3, 1)*XPN(3, 4)
ACR24=XPN(1, 2)*XPN(1, 4)+XPN(2, 2)*XPN(2, 4)+XPN(3, 2)*XPN(3, 4)
ACR34=XPN(1, 3)*XPN(1, 4)+XPN(2, 3)*XPN(2, 4)+XPN(3, 3)*XPN(3, 4)
CS(1)=ACR24-ACR14*ACR12
CS(2)=ACR13-ACR23*ACR12
CS(3)=ACR24-ACR34*ACR23
CS(4)=ACR13-ACR34*ACR14
B241=XPN(2, 2)*XPN(3, 4)-XPN(3, 2)*XPN(2, 4)
B242=XPN(3, 2)*XPN(1, 4)-XPN(1, 2)*XPN(3, 4)
B243=XPN(1, 2)*XPN(2, 4)-XPN(2, 2)*XPN(1, 4)
B131=XPN(2, 1)*XPN(3, 3)-XPN(3, 1)*XPN(2, 3)
B132=XPN(3, 1)*XPN(1, 3)-XPN(1, 1)*XPN(3, 3)
B133=XPN(1, 1)*XPN(2, 3)-XPN(2, 1)*XPN(1, 3)
SN(1)=XPN(1, 1)*B241+XPN(2, 1)*B242+XPN(3, 1)*B243
SN(2)=-(XPN(1, 2)*B131+XPN(2, 2)*B132+XPN(3, 2)*B133)
SN(3)=-(XPN(1, 3)*B241+XPN(2, 3)*B242+XPN(3, 3)*B243)
SN(4)=XPN(1, 4)*B131+XPN(2, 4)*B132+XPN(3, 4)*B133
50 CONTINUE
D TYPE 8844, SN(1), CS(1)
D TYPE 8844, SN(2), CS(2)
D TYPE 8844, SN(3), CS(3)
D TYPE 8844, SN(4), CS(4)
8844 FORMAT(' SN, CS= ', 2F15. 8)
SUM=SN(1)+SN(2)+SN(3)+SN(4)
IF(ABS(SUM).GT.0.01) GO TO 25
IF(ABS(CS(1)).GT. ABS(SN(1))) GO TO 25
IF(ABS(CS(2)).GT. ABS(SN(2))) GO TO 25
IF(ABS(CS(3)).GT. ABS(SN(3))) GO TO 25
1090 G=SUM*.25
IF(NSIDE.EQ.3) G=SUM*.166666667
RETURN
25 ST=SN(NSIDE)
DO 30 I=1,NSIDE
+ IF((ABS(CS(I)).LT.9E-8).AND.(ABS(SN(I)).LT..9E-05))  

+ GO TO 1090
IF(ST*SN(I).LT.0.) GO TO 1090
ST=SN(I)
C2=CS(I)/SQRT(SN(I)**2+CS(I)**2)
G=G+ACOS(C2)
30 CONTINUE
RETURN
END

```

```

      SUBROUTINE EBD
C INITIALIZE PANELS AND COMPUTE BODY MATRIX
C
      * COMMON/BD/XPAN(120), YPAN(120), ZPAN(120), AREA(120), ST(120),
      * ACN(120), ACNW(120), AN(120,3), E(120), P(120,6), PRFS(120),
      * STOLD(120), PX(120,6)
      * COMMON/BD2/XPT(150), YPT(150), ZPT(150), WRF(150), WRFR(150),
      * KK(150,4)
      * COMMON/A/NPAN, NPT, GEE, RHO, NKX, NKY, EYE, DT, TIM, UFWD
      DIMENSION EP(120), EPP(120)
      COMPLEX EYE
C READ IN BODY PANEL PARAMETERS
101   FORMAT(4I5)
100   FORMAT(3F10.0)
103   FORMAT(3F10.2)
104   FORMAT(I3)
C NUMBER OF POINTS AND PANELS
      READ(2, 101) NPT, NPAN
      TYPE 101, NPT, NPAN
C COORDINATES OF POINTS
      READ(2, 100) (XPT(N), YPT(N), ZPT(N), N=1, NPT)
      DO 7777 N=1, NPT
      TYPE 103, XPT(N), YPT(N), ZPT(N)
7777   CONTINUE
C DEFINE CORNER PINTS OF EACH PANEL
      READ(2, 101) (KK(N, 1), KK(N, 2), KK(N, 3), KK(N, 4), N=1, NPAN)
C COMPUTE PANEL AREAS
      DO 150 J=1, NPAN
      K1=KK(J, 1)
      K2=KK(J, 2)
      K3=KK(J, 3)
      K4=KK(J, 4)
      IF(K4.EQ.0) GO TO 8
      XPAN(J)=(XPT(K1)+XPT(K2)+XPT(K3)+XPT(K4))*0.25
      YPAN(J)=(YPT(K1)+YPT(K2)+YPT(K3)+YPT(K4))*0.25
      ZPAN(J)=(ZPT(K1)+ZPT(K2)+ZPT(K3)+ZPT(K4))*0.25
      GO TO 9
C TRIANGULAR PANELS
8     XPAN(J)=((XPT(K1)+XPT(K2)+XPT(K3))/3.0
      YPAN(J)=((YPT(K1)+YPT(K2)+YPT(K3))/3.0
      ZPAN(J)=((ZPT(K1)+ZPT(K2)+ZPT(K3))/3.0
      K4=K3
      9     XA=XPT(K3)-XPT(K1)
      XB=XPT(K4)-XPT(K2)
      YA=YPT(K3)-YPT(K1)
      YB=YPT(K4)-YPT(K2)
      ZA=ZPT(K3)-ZPT(K1)
      ZB=ZPT(K4)-ZPT(K2)
      -----
C COMPUTE PANEL AREAS
      AZ=XA*YB-YA*XB
      AX=YA*ZB-ZA*YB
      AY=ZA*XB-XA*ZB
      ARE=SQRT(AX*AX+AY*AY+AZ*AZ)
      AREA(J)=ARE*0.50
      AN(J, 1)=-AX/ARE
      AN(J, 2)=-AY/ARE
      AN(J, 3)=-AZ/ARE
150   CONTINUE
808   FORMAT(1X, I5, SF11.4)
      DO 1308 J=1, NPAN
      JJJ=J
      CALL PREP(JJJ)
      ST(J)=0.00
      DO 1308 K=1, 6
      PX(J, K)=0.00
1308   CONTINUE
      DO 308 J=1, NPAN
      JJJ=J
      AX=-AN(J, 1)
      AY=-AN(J, 2)
      AZ=-AN(J, 3)
      XF=XPAN(J)
      YF=YPAN(J)
      ZF=ZPAN(J)
      DO 157 L=1, NPT
      WRF(L)=SQRT((XPT(L)-XF)**2+(YPT(L)-YF)**2+(ZPT(L)-ZF)**2)
      WRFR(L)=SQRT((XPT(L)-XF)**2+(YPT(L)-YF)**2+(ZPT(L)+ZF)**2)
157

```

```

      DO 500 I=1,3
500   WRITE(3) (AN(J, I), J=1, NPAN)
CONTINUE
      WRITE(3) (XPAN(J), J=1, NPAN)
      WRITE(3) (YPAN(J), J=1, NPAN)
      WRITE(3) (ZPAN(J), J=1, NPAN)
      WRITE(3) (AREA(J), J=1, NPAN)
      DO 309 JL=1, NPAN
      JLJ=JL
      CALL GE(XF, YF, ZF, JLJ, VX, VY, VZ, VXR, VYR, VZR, JJJ)
      VX=VX+VXR
      VY=VY+VYR
      VZ=VZ+VZR
C      COMPUTE NORMAL VELOCITY AT PANEL J DUE TO PANEL JL
      E(JL)=AX*VX+AY*VY+AZ*VZ
C INCREMENT PX MATIRX
      FR1=-AREA(J)*VX*AN(J, 1)
      FR2=-AREA(J)*VX*AN(J, 2)
      FR3=-AREA(J)*VX*AN(J, 3)
      PX(JL, 1)=PX(JL, 1)+FR1
      PX(JL, 2)=PX(JL, 2)+FR2
      PX(JL, 3)=PX(JL, 3)+FR3
      PX(JL, 4)=PX(JL, 4)+YF*FR3-ZF*FR2
      PX(JL, 5)=PX(JL, 5)+ZF*FR1-XF*FR3
      PX(JL, 6)=PX(JL, 6)+XF*FR2-YF*FR1
309   CONTINUE
      WRITE(99) (E(JL), JL=1, NPAN)
308   CONTINUE
      DO 2424 K=1, 6
2424   WRITE(3) (PX(JL, K), JL=1, NPAN)
      CLOSE (UNIT=99)
C      INVERT E MATRIX
      CALL MATIN(NPAN)
      RETURN
      END

```

```

      SUBROUTINE MATIN(NPAN)
C INVERST MATRIX
      DIMENSION E(120, 120), BB(120), EST(120)
      OPEN(UNIT=99, FILE='SCR', FORM='UNFORMATTED', TYPE ='OLD')
      DO 120 J=1, NPAN
120     READ(99) (E(J, I), I=1, NPAN)
      DO 130 J=1, NPAN
      DO 11 MM=1, NPAN
      EST(MM)=0.00
11       BB(MM)=0.00
      BB(J)=1.0
      EST(J)=1.0/E(J, J)
      DO 17 NIT=1, 6
      DO 17 K=1, NPAN
      B=BB(K)
      DO 15 I=1, NPAN
15       IF(I, NE, K) B=B-E(K, I)*EST(I)
      EST(K)=B/E(K, K)
17       CONTINUE
      WRITE(3) (EST(K), K=1, NPAN)
130   CONTINUE
      RETURN
      END

```

```

C
      SUBROUTINE GE(XF, YF, ZF, J, V1, V2, V3, V1R, V2R, V3R, NBT)
      COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
*     ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
*     STOLD(120),PX(120,6)
      COMMON/BD2/XPT(150),YPT(150),ZPT(.50),WRF(150),WRFR(150)
*     ,KK(150,4)
      COMMON/ARE/RR(500),XZJ(200),YXJ(200),ZYJ(200)
      DIMENSION XSA(3,4),XFA(3),XSAR(3,4)
      J4=J*4
      V1=0.00
      V2=0.00
      V3=0.00
      V1R=0.00
      V2R=0.00
      V3R=0.00
      XNJ=AN(J,1)
      YNJ=AN(J,2)
      ZNJ=AN(J,3)
      NSIDE=4
      IF(KK(J,4).EQ.0) NSIDE=3
      DO 20 JJ=1,NSIDE
      J2=1
      IF(JJ.LT.NSIDE) J2=JJ+1
      J4=J4+1
      KF=KK(J,J2)
      AF=XPT(KF)
      BF=YPT(KF)
      CF=ZPT(KF)
      R=RR(J4)
      KG=KK(J,J2)
      ANX=(AF-XPT(KG))/R
      ANY=(BF-YPT(KG))/R
      ANZ=(CF-ZPT(KG))/R
      A=AF-XF
      B=BF-YF
      C=CF-ZF
      TX=XZJ(J)*ANZ-YXJ(J)*ANY
      TY=YXJ(J)*ANX-ZYJ(J)*ANZ
      TZ=ZYJ(J)*ANY-XZJ(J)*ANX
      EX1=A*ANX+B*ANY+C*ANZ
      CALL GO(EX1,R,FF,WRF(KF),WRF(KG))
      V1=V1+FF*TX
      V2=V2+FF*TY
      V3=V3+FF*TZ
      XSA(1,JJ)=-A/WRF(KF)
      XSA(2,JJ)=-B/WRF(KF)
      XSA(3,JJ)=-C/WRF(KF)
      EX1R=EX1+2.0*ZF*ANZ
      CR=-CF-ZF
      CALL GO(EX1R,R,FR,WRFR(KF),WRFR(KG))
      V1R=V1R-FR*TX
      V2R=V2R-FR*TY
      V3R=V3R+FR*TZ
      XSAR(1,JJ)=-A/WRFR(KF)
      XSAR(2,JJ)=-B/WRFR(KF)
      XSAR(3,JJ)=CR/WRFR(KF)
20    CONTINUE
      G=6.283185307
      IF(J.EQ.NBT) GO TO 84
      CALL SOLID(XSA,G,NSIDE)
      AGG=A*XNJ+B*YNJ+C*ZNJ
      G=-SIGN(G,AGG)
84    CONTINUE
      CALL SOLID(XSAR,GR,NSIDE)
      AGGR=A*XNJ+B*YNJ-CR*ZNJ
      GR=SIGN(GR,AGGR)
85    CONTINUE
7371  FORMAT(' G,GR=',2F15.5)
      V1=V1+XNJ*G
      V2=V2+YNJ*G
      V3=V3+ZNJ*G
      V1R=V1R+XNJ*GR
      V2R=V2R+YNJ*GR
      V3R=V3R-ZNJ*GR
5590  FORMAT(' V1,V2,V3=',3F15.5)
5591  FORMAT(' V1R,V2R,V3R=',3F15.5)
      RETURN
      END

```

```

C
SUBROUTINE POTST
COMMON/BD/XPAN(120),YPAN(120),ZPAN(120),AREA(120),ST(120),
* ACN(120),ACNW(120),AN(120,3),E(120),P(120,6),PRFS(120),
* STOLD(120),PX(120,6)
COMMON/BD2/XPT(150),YPT(150),ZPT(150),WRF(150),WRFR(150),
* KK(150,4)
COMMON/A/NPAN,NPT,GEE,RHO,NKX,NKY,EYE,DT,TIM,UFWD
COMPLEX A,B,EYE
DIMENSION XPSL(3,4),XPSLR(3,4),PBB(120,120)
COMMON/PTST/ARE4(200,4),X4(200,4),Y4(200,4),Z4(200,4)
*,SEL(200,4)
DO 1500 J=1,NPAN
ARE4(J,4)=-1.0
JT=4
IF(KK(J,4).EQ.0) JT=3
DO 1500 JJ=1,JT
J2=1
IF(JJ.LT.JT) J2=JJ+1
KF=KK(J,J2)
KG=KK(J,J2)
X4(J,JJ)=(XPT(KF)+XPT(KG)+XPAN(J))/3.0
Y4(J,JJ)=(YPT(KF)+YPT(KG)+YPAN(J))/3.0
Z4(J,JJ)=(ZPT(KF)+ZPT(KG)+ZPAN(J))/3.0
AF=XPT(KF)-XPAN(J)
BF=YPT(KF)-YPAN(J)
CF=ZPT(KF)-ZPAN(J)
AG=XPT(KG)-XPAN(J)
BG=YPT(KG)-YPAN(J)
CG=ZPT(KG)-ZPAN(J)
CALL SELF(AF,BF,CF,AG,BG,CG,FEE)
SEL(J,JJ)=FEE
CR=AF*BG-BF*AG
AR=BF*CG-CF*BG
BR=CF*AG-AF*CG
ARE4(J,JJ)=0.5*SQRT(AR*AR+BR*BR+CR*CR)
1500 CONTINUE
DO 127 NJ=1,NPAN
DO 1277 MJ=1,NPAN
PBB(NJ,MJ)=0.00
1277 P(NJ,1)=0.00
P(NJ,2)=0.00
P(NJ,3)=0.00
P(NJ,4)=0.00
P(NJ,5)=0.00
P(NJ,6)=0.00
DO 128 NK=1,4
ARN=ARE4(NJ,NK)
IF(ARN.LT.0.0) GO TO 128
P1=0.0
P2=0.0
P3=0.0
P4=0.0
P5=0.0
P6=0.0
X=X4(NJ,NK)
Y=Y4(NJ,NK)
Z=Z4(NJ,NK)
DO 138 MJ=1,NPAN
DO 138 MK=1,4
XF=X4(MJ,MK)
YF=Y4(MJ,MK)
ZF=Z4(MJ,MK)
ARM=ARE4(MJ,MK)
IF(ARM.LT.0.00) GO TO 138
IF(NJ.NE.MJ) GO TO 140
IF(MK.NE.NK) GO TO 140
FRA=SEL(MJ,MK)/ARM
GO TO 1380

```

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**12-90**

**DTIC**